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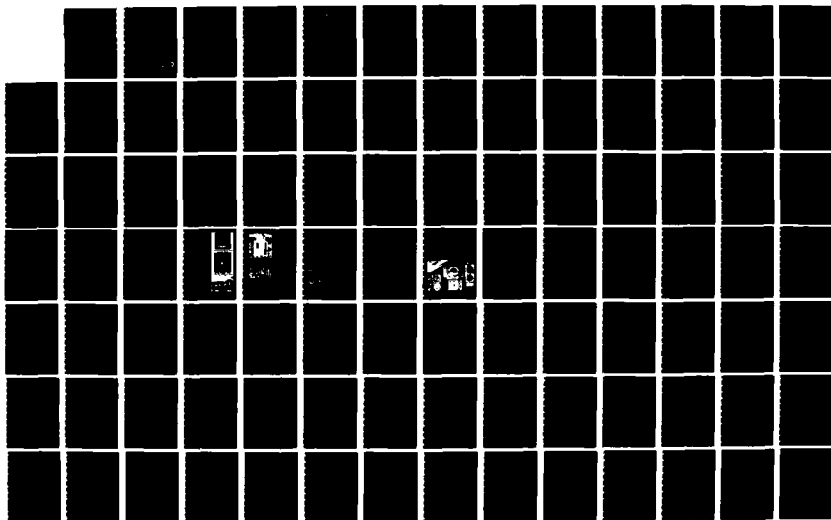
EVALUATION OF SIKORSKY S-76A 24 MISSED APPROACH
PROFILES FOLLOWING PRECIS (U) FEDERAL AVIATION
ADMINISTRATION TECHNICAL CENTER ATLANTIC CIT

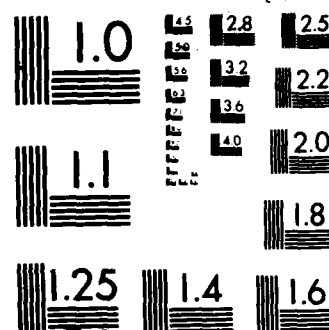
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Evaluation of Sikorsky S-76A 24 Missed Approach Profiles Following Precision MLS Approaches to a Helipad at 40 KIAS

Michael M. Webb

October 1986

DOT/FAA/CT-TN86/31

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US Department of Transportation
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Technical Center
Atlantic City Airport, N.J. 08405

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1. Report No. DOT/FAA/CT-TN86/31	2. Government Accession No. AD-A175407	3. Recipient's Catalog No.	
4. Title and Subtitle EVALUATION OF SIKORSKY S-76A 24 MISSED APPROACH PROFILES FOLLOWING PRECISION MLS APPROACHES TO A HELIPAD AT 40 KIAS		5. Report Date October 1986	
		6. Performing Organization Code ACT-140	
		8. Performing Organization Report No. DOT/FAA/CT-TN86/31	
7. Author(s) Michael M. Webb		10. Work Unit No. (TRAIS)	
9. Performing Organization Name and Address U.S. Department of Transportation Federal Aviation Administration Technical Center Atlantic City Airport, NJ 08405		11. Contract or Grant No. T0701B	
		13. Type of Report and Period Covered Technical Note August 1985-July 1986	
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Program Engineering and Maintenance Service Washington, DC 20590		14. Sponsoring Agency Code APM-450	
15. Supplementary Notes			
16. Abstract <p>This report describes the "trend analysis" evaluation of the Sikorsky S-76A missed approach profiles following precision microwave landing system (MLS) approaches at glidepath angles of 3°, 6° and 7.5° at a minimum instrument meteorological conditions airspeed (V_{mini}) of 40 knots indicated airspeed (KIAS). It describes the flight test facilities, methodology, and addresses topics such as how flight test data are collected and what is done with it. It also describes each of the helicopter procedures flown during the project and provides an analysis of the pilots subjective opinions concerning the acceptability and workload associated with these procedures.</p> <p>It was concluded that the "trend" indicates that no current terminal instrument procedures (TERPS) criteria would be violated by reducing V_{mini} to 40 KIAS. The plots indicated that there were no penetrations of the 20:1 surface missed approach surface. The maximum deviation allowed by TERPS for the height loss at missed approach rises along a 20:1 plane which begins at the surface or 250 feet below the missed approach point. For this test that meant that the 20:1 obstacle free surface began at ground level. At most, only a 40-foot fly under at decision height (DH) was noticed during the 24 missed approaches flown.</p> <p>However, this information should be considered indicative rather than conclusive due to the small sample size (24 approaches). Additional testing would be required to provide TERPS quality data.</p>			
17. Key Words MLS Helicopter Helicopter Certification Precision MLS Approaches		18. Distribution Statement This document is available to the U.S. Public through the National Technical Information Service, Springfield, Va. 22161	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 100	22. Price

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EXECUTIVE SUMMARY

In August 1985, the Guidance and Airborne Systems Branch (ACT-140) received a formal request through Federal Aviation Administration (FAA) Headquarters, Helicopter Program Branch (APM-720), from the Southwest Region Rotorcraft Directorate (ASW-110) to supply a "trend analysis" to demonstrate a trend, if any, associated with the decision height (DH) through missed approach phases of precision approaches flown in a production S-76A at a minimum instrument meteorological conditions airspeed (V_{mini}) of 40 knots indicated airspeed (KIAS). This work was prompted by the certification testing of the S-76A for a lower V_{mini} conducted by the New England Certification Office (ANE-150) performed at Battery Park Heliport, New York, in May 1985. During this test phase only four missed approaches were flown.

An additional 24 missed approaches were recorded, flown by three subject pilots, at 3°, 6° and 7.5° glidepaths using microwave landing system (MLS) precision guidance to a heliport.

Airborne data has been reduced to graphic plots that provide a visual description of the approach and summarized mathematically to provide statistics regarding performance indicators. These data were forwarded to ASW-110.

The data demonstrated that subject pilots, with minimal training, were able to transition from a raw-data guided MLS precision approaches at elevation (glidepath) angles ranging from 3° to 7.5° to the missed approach without excessive difficulty or excessive loss of altitude.

The results of the analysis contained in this report can be used to further refine and establish procedures for reducing the V_{mini} when flying precision approaches to heliports.

INTRODUCTION

This flight test program was a follow-on to the evaluation of the Sikorsky S-76A by the New England Region Certification Office (ANE-150) evaluating the aircraft for instrument final approach speeds below minimum instrument meteorological conditions airspeed (V_{mini}). This test was conducted from May 21 through May 31, 1985. The program was initiated in response to Sikorsky letter COL-85-8500 dated April 2, 1985. The evaluation criteria was provided in a letter from the Southwest Rotorcraft Directorate (ASW-110), see appendix A-1. The test helicopter was a Sikorsky S-76A, serial number 760053, registration number 6702. Eight flights for a total of 12.2 hours of flight time were flown, which included two instrument landing system (ILS) approaches and 36 microwave landing system (MLS) approaches flying 6° and 9° glideslopes utilizing the MLS at Battery Park Heliport (reference 1). Based on the testing, ANE-150 recommended to ASW-110 that the Sikorsky S-76A, equipped with the Sperry SPZ-7000 Dual Digital Automatic Flight Control System (DDAFCS) operating in the ATT mode, demonstrated acceptable flight characteristics during instrument final approaches using airspeeds between V_{mini} and 40 knots indicated airspeed (KIAS) with the following limitations:

1. A minimum crew of two helicopter instrument rated pilots.
2. A minimum approach airspeed of 40 KIAS.
3. A maximum crosswind component of 15 knots.
4. A maximum glidepath of 7.5°.
5. A suitable groundspeed indicator must be available (i.e., precision distance measuring equipment (DME/P), distance measuring equipment (DME), or Loran C or Area Navigation (RNAV)).
6. A suitable indication of a deceleration point prior to glidepath interception (DME, very high frequency omnidirectional range (VOR) radial, nondirection beacon (NDB), marker beacon (MB), etc.).
7. Installation of approved instrument precision approach receiver equipment (ILS or MLS).
8. An approved instruction manual (rotorcraft flight manual (RFM) supplement, etc.) must be available.
9. The Sperry SPZ-7000 flight director may be used in the 3 cue mode, but may not be coupled to the automatic flight control system (AFCS). Coupled AFCS (automatic pilot) approaches below V_{mini} are not authorized. Flight director 2 cue (azimuth and glidepath) approaches are not authorized at airspeeds below V_{mini} .

In August 1985, ACT-140 received a request from the ASW-110 to supply a "trend analysis" to demonstrate a trend, if any, associated with the decision height (DH) through missed approach phases of precision approaches flown in a production S-76A at a V_{mini} of 40 KIAS (see appendix B). During the Certification Office test phase only four missed approaches were flown. To

obtain additional missed approach data, 24 approaches were flown at 3°, 6°, and 7.5° glidepaths to a collocated MLS installed at the Interim Concept Development Heliport at the FAA Technical Center.

OBJECTIVE.

The purpose of these tests flights was to augment data collected by United Technologies Corporation, Sikorsky Division, during flying 40-knot minimum instrument (V_{mini}) airspeed certification test flights. The original certification tests flights were conducted in May 1985 at the Battery Park Heliport in New York City.

BACKGROUND.

Below are the main issues relating to decreasing the V_{mini} of the S-76A helicopter from 60 KIAS to 40 KIAS.

1. There are two reasons to reduce V_{mini} . The primary reason is to reduce the distance required to decelerate from DH to full stop at a heliport. The existing V_{mini} for most S-76A aircraft (60 KIAS) requires approximately 3000 feet (assuming a 0.05g deceleration limit) to decelerate to a hover in a normal manner (see appendix D). However, decelerating from 40 KIAS only requires approximately 1500 feet to perform the same maneuver. This distance remains essentially constant regardless of the approach angle the pilot has selected. Thus, as the approach angle increases, the height above landing (HAL) at which the pilot must have visual contact with the landing environment also increases. With the lower V_{mini} , just as the distance to decelerate can be reduced by one-half, the HAL can be reduced by one-half. As a result, the approach minimums for steep angle approaches can be reduced below the minimums which can be obtained with a higher V_{mini} . Another reason to reduce V_{mini} is to reduce the rate of descent required to maintain the desired glidepath. The maximum desired rate of descent has been determined through prior testing to be no greater than 900 feet per minute (fpm). Flying a V_{mini} of 60-knot indicated airspeed (IAS) and a 15-knot tailwind on a 6° approach angle, the rate of descent is 795 fpm. Without the tailwind the rate of descent is 635 fpm. However, with a V_{mini} of 40 KIAS with a 15 knot tailwind, the maximum rate of descent would be only 581 fpm. Without the tail wind the rate of descent is 421 fpm. A V_{mini} of 40 KIAS allows a greater acceptable tailwind component to be present when flying steeper glidepaths than would allowed with a V_{mini} of 60 KIAS.
2. Another potential issue in reducing V_{mini} is that aircraft stability is affected by the reduction of airspeed, and additional equipment may be required to provide the necessary static and dynamic stability. As any helicopter reduces its approach speed to less than the best lift over drag speed (74 KIAS for the S-76A), aircraft stability is reduced. This stability reduction may require additional aircraft equipment to reduce the resultant workload on the pilot. The current V_{mini} is aircraft equipment dependent. For the S-76A equipped with a 3 cue (3 axis) flight director system and AFCS, a reduction of V_{mini} to 50 knots is permitted. For an S-76A equipped with only a 2 cue (2 axis) flight director, with or without AFCS, a V_{mini} of 60 KIAS is permitted.

3. When flying steep angle approaches at a V_{mini} of less than the best lift over drag speed (V_y) (figure 1), National Aeronautics and Space Administration (NASA)/Federal Aviation Administration (FAA) flight tests have shown that different flight techniques must be used. Flight on the backside of the power curve requires strict airspeed control. Small vertical corrections required to track a glide slope are not made with airspeed/pitch attitude change as can be done when operating on the front side of the power required curve. Power/collective must be the primary control used in glide slope tracking during low speed (airspeeds less than V_y) approaches. Lower approach speeds greatly amplify the effect of any wind. Another wind related problem occurs as the windspeed nears the approach airspeed, the ground speed of the helicopter may become so slow that the rate of closure to the landing site is unacceptably low. The relative direction of the wind to the helicopter and desired approach path may also induce significant tracking problems, such as, when the crosswind velocity equals the forward velocity of the helicopter. In this case, the required correction to stay on the course centerline is 90° off the no wind inbound heading and, of course, the helicopter would never get to the heliport unless the aircraft was flown in a "sideslip" to maintain the course to the heliport.

These changes in techniques will require additional pilot training and additional aircraft equipment (i.e., a 3-axis flight director optimized for low speed approaches) to achieve lower V_{mini} . Both requirements touch on regulatory issues.

METHODS

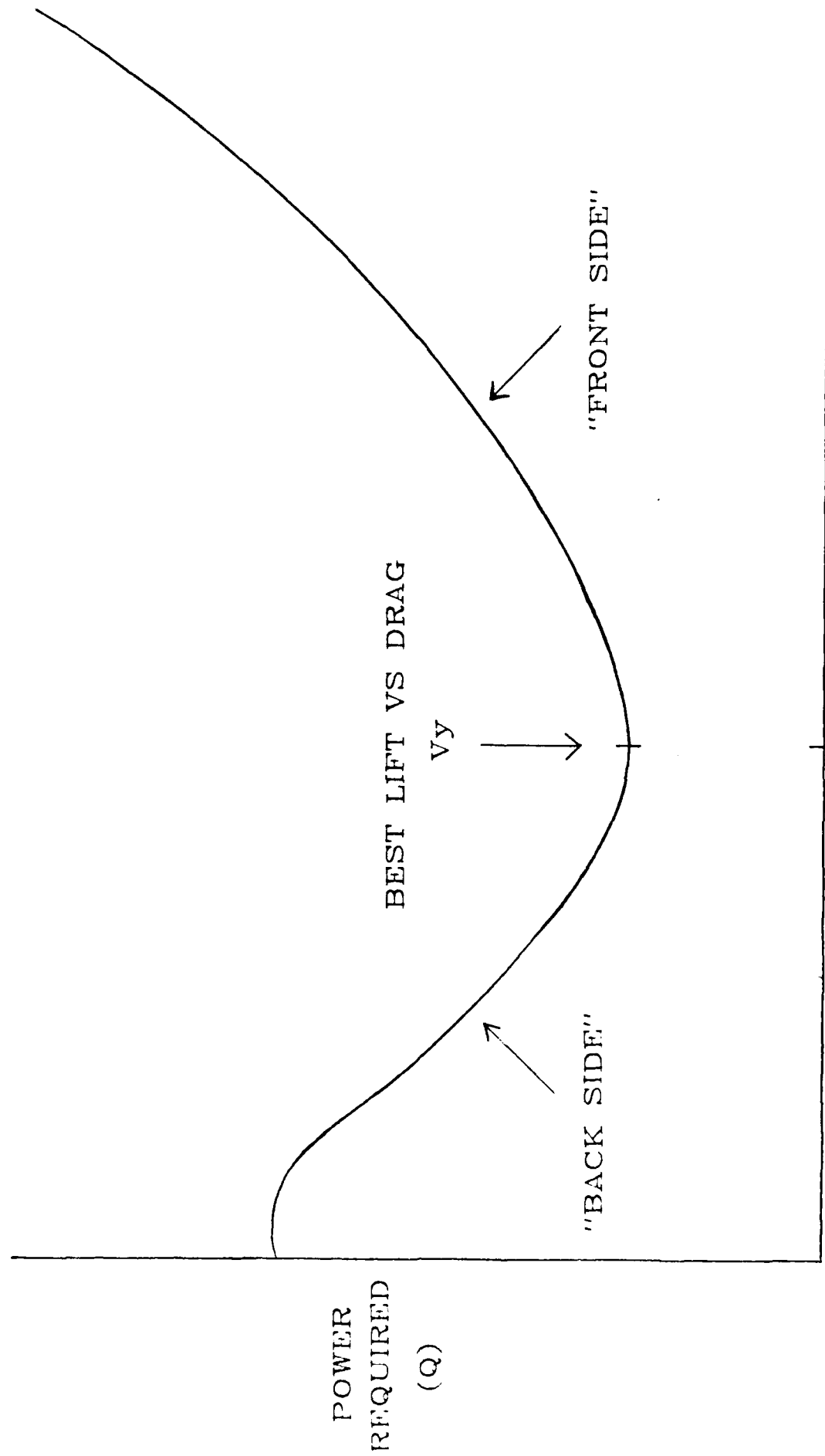
SYSTEM EQUIPMENT DESCRIPTION.

GROUND ELECTRONICS. The MLS utilized for this project was developed for the Department of Transportation (DOT)/FAA by the Hazeltine Corporation. This is a prototype model 2400 MLS consisting of two basic functional elements, elevation (EL) and azimuth (AZ), supplemented with DME/P. These elements are collocated beside the heliport. This system radiates the compatible Timed Reference Scanning Beam (TRSB) format consisting of a preamble and a TO-FRO scanning beam in each case. This system provides proportional guidance through approximately $\pm 10^\circ$ AZ, and 1° to $\pm 15^\circ$ in EL. DME/P was provided by a U.S. Marine Corps Approach Landing System (a tactical MLS with DME/P) situated above the AZ and EL antennas providing slant range distance measurements to both antennas (see figure 2).

A modified Bendix MLS Service Test and Evaluation Program (STEP) receiver was utilized for this test. The receiver was modified utilizing the original 08A STEP format with the course widths set to $\pm 3.6^\circ$ AZ and an EL course width of \pm selected angle/3. The course deviation information was displayed on the pilot horizontal situation indicator (HSI). See figure 3.

TEST AIRCRAFT. The aircraft utilized during this flight test was a production Sikorsky S-75A, serial number 7600087, registration number N-38. It is equipped with a Sperry SHZ-760 Helipilot/Helcis II Automatic Flight Control

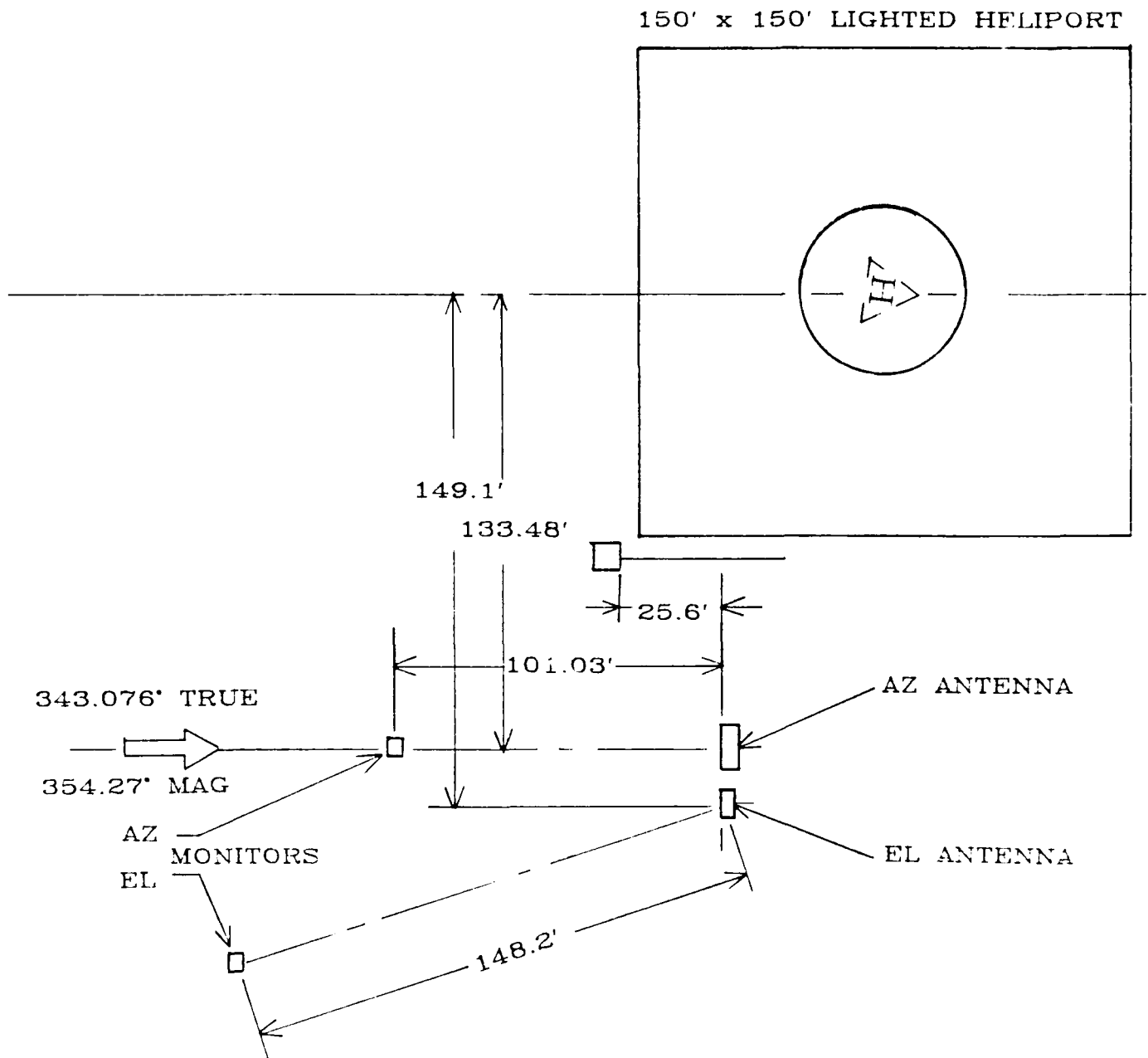
HELICOPTER PERFORMANCE CURVE



74 KIAS for S-76

AIRSPEED (A/S)

FIGURE 1. HELICOPTER PERFORMANCE CURVE



ACT--140 COLLOCATED
MLS HELIPORT
MLS CHANNEL 590
DME /P 111.95

CONCEPT DEVELOPMENT HELIPORT

1. HELI. 2. 3. 4. 5. 6. 7. 8. 9. 10. 11. 12. 13. 14. 15. 16. 17. 18. 19. 20. 21. 22. 23. 24. 25. 26. 27. 28. 29. 30. 31. 32. 33. 34. 35. 36. 37. 38. 39. 40. 41. 42. 43. 44. 45. 46. 47. 48. 49. 50. 51. 52. 53. 54. 55. 56. 57. 58. 59. 60. 61. 62. 63. 64. 65. 66. 67. 68. 69. 70. 71. 72. 73. 74. 75. 76. 77. 78. 79. 80. 81. 82. 83. 84. 85. 86. 87. 88. 89. 90. 91. 92. 93. 94. 95. 96. 97. 98. 99. 100.

[illegible]

FIGURE 3. ISL INDICATOR

System and a HELCIS Flight Director. However, for this test only raw data information was displayed on the pilot's HSI. The aircraft is certified for single pilot instrument flight rule (IFR) operations with a minimum instrument meteorological conditions (IMC) airspeed (V_{mini}) of 60 knots and is representative of the IFR certified helicopters currently in use.

The Flight Control System (FCS) in this test aircraft differed from the FCS used in the certification test aircraft, the Sperry SPZ-7000. These systems are fully described in reference 2. The SHZ-760 is a dual Helipilot system consisting of two independent control systems, each fully capable of controlling the helicopter pitch and roll axes. Each Helipilot has separate electrical systems and gyro references. The Helipilots feed servos mounted in series with the aircraft control rods. Automatic trim of the roll and pitch axes refines control accuracy and further reduces pilot workload. The SHZ-760 system also contains a complete flight director which can operate independent of the Helipilots to provide the pilot with visual flight director commands. For fully automatic flightpath control, the flight director system is coupled to the Helipilot system.

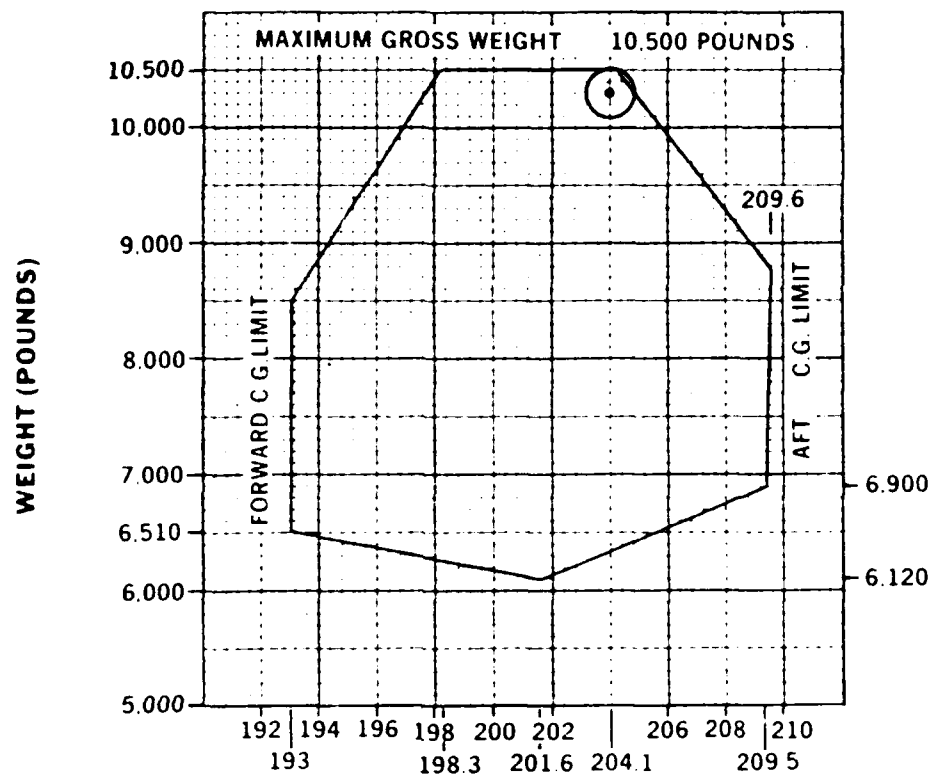
The Sperry SPZ-7000 DDAFCS is a completely integrated digital autopilot/flight director/air data/auto trim system which has a full complement of horizontal and vertical flight guidance modes. These include all radio guidance modes, Loran C, RNAV tracking and air data oriented vertical modes. However, attitude mode and coupled collective are also available to the pilot. When engaged and coupled, the flight director will control the aircraft using the same commands displayed on the attitude director indicator. The instruments act as a means to monitor the performance of the autopilot. When the autopilot is not engaged, the same modes of operation are available for the flight director only. The pilot maneuvers the aircraft to satisfy the flight director commands, as does the autopilot when it is engaged.

The biggest control differences between the SHZ-760 and the SPZ-7000 are:

<u>SHZ-760</u>	<u>SPZ-7000</u>
AFCS in 2 axes (pitch, roll)	AFCS in 4 axes (pitch, roll, yaw, collective)
Heading hold (roll axis)	Heading hold (yaw)
Collective cue in (goaround (GA) only (not coupled)	Collective cue in all modes (coupled)
Not Compatible with the Electronic Flight Instru- mentation System	Compatible with the Electronic Flight Instrumentation System

The aircraft was operated between approximately 500 to 1500 pounds below the maximum gross weight of 10,300 pounds. However, this was not considered as a critical parameter in the test since no one engine inoperative (OEI) procedures were flown. The center of gravity (CG) for each flight was approximately 204 inches (see figure 4).

SUBJECT PILOTS. The subject pilots selected for this test were local FAA pilots. It was decided to utilize local pilots due to the small number of approaches to be performed. Each pilot was qualified in the S-76A and familiar



NOTE:

AIRCRAFT STA (INCHES)

THE AFT C.G. LIMIT HAS BEEN ADJUSTED TO ACCOUNT FOR THE LANDING GEAR RETRACTION HORIZONTAL MOMENT/100 OF PLUS (+) 33 THEREFORE LOADINGS BASED ON WHEELS-DOWN CONDITIONS WHICH FALL WITHIN THE LIMITING C.G. OF THIS ENVELOPE WILL BE WITHIN C.G. LIMITS FOR FLIGHT WITH THE LANDING GEAR RETRACTED

Weight and Center of Gravity Envelope

FIGURE 4. WEIGHT AND CENTER OF GRAVITY ENVELOPE

with steep angle approach techniques. Each pilot possessed at least a rotorcraft commercial/instrument flight rating. The pilots had an average of 200 hours of instrument time (actual or simulated).

AIRCRAFT TRACKING. Two different ground-based aircraft tracking systems were used simultaneously during this test. The systems used were an optical system, A GTE Precision Automated Tracking System (PATS), and a radar system called Extended Area Instrumentation Radar (EAIR). Using both systems provided redundancy and permitted a higher degree of continuous tracking coverage. A primary tracking system was identified dependent on target location. For areas within 2 nautical miles (nmi) of the MLS ground equipment and the area containing the missed approach segment PATS tracking was selected to be the primary system, while EAIR was used to fill in where PATS data were not available.

EAIR TRACKER. The Technical Center's EAIR is a model 661, precision C-band instrumentation radar system that was designed to measure, record, and display an aircraft's position in slant range and AZ and EL angles. In the primary tracking mode (skin track), EAIR has a maximum tracking distance of 100 nmi. In the secondary mode (beacon), it has a range of 190 nmi. In either mode it has a minimum tracking distance of 1 nmi. Recorded data are sent to the computer facility and post-flight processed in the same manner as the PATS data. A detailed description of both tracking systems is presented in reference 3.

GTE (PATS). The GTE PATS is a mobile laser tracking and ranging system. It gathers, records, and displays space position information on a wide variety of vehicles and targets in real time with great accuracy. Self-contained in a mobile van, PATS requires two operators. PATS measures AZ, EL, and range automatically by transmitting a laser pulse to a target and measuring the angle of return and the round trip time. These data are then recorded on a Digital PDP 11/34 system and processed to be merged with EAIR data and the airborne data to yield airborne position plots, system error, and flight technical error. Performance characteristics of the PATS tracker are depicted in table 1.

APPROACH PROCEDURES. Twenty-four approaches for data were flown each beginning from a turn on to the final approach course at 4 nmi. The aircraft was slowed to 40 KIAS by the preglideslope intercept deceleration point (2.5 DME). The flight test profiles are depicted in table 2. Approach plates for the three different EL angles flown to the heliport are shown in figures 5 to 7. The 40 KIAS was maintained throughout the duration of the approach to DH. At DH a straight ahead climb was initiated to 500 feet MSL followed by a climbing left turn to heading 160° leveling off at 1600 feet m.s.l. Following the approaches to the heliport, two subjects flew one approach to runway 31 to perceive workload differences flying at V_{min} of 40 KIAS to a split site MLS. The approach plate for the runway 31 approach is presented in figure 8. These approaches were not tracked due to the alignment of the trackers. However, the subjects' comments were recorded by the airborne data technician.

All flying was performed with the Stability Augmentation System (SAS) flight control system selected.

TABLE 1. PATS TRACKER PERFORMANCE CHARACTERISTICS

1. Absolute Accuracy:

Azimuth: 0.1 milliradian (mrad) for all ranges
 Elevation: 0.1 mrad for all ranges
 Range: ± 0.5 meters for target ranges of 200 to 10,000 meters
 ± 1 meter for target ranges of 10,000 to 30,000 meters

2. Data Sample Rate:

100, 50, 20, or 10 sample sets per second, selectable.

3. Angular Coverage:

AZ: $\pm 420^\circ$
 EL: -5° to $+85^\circ$

4. Acquisition Dynamics (manual or automatic)

Maximum angular rate (AZ and EL): 2 radians/second.
 Maximum angular acceleration (AZ and EL): 500 mrad/sec²

TABLE 2. FLIGHT TEST PROFILES

Run No.	EL Angle (deg)	No Wind Rate of Descent (fpm)	DH (ft)	Distance to Decel. (ft)*
1	3.0	200	200	3818
2	7.5	550	200	1520
3	6.0	450	200	1902
4	7.5	550	200	1520
5	3.0	200	200	3818
6	6.0	450	200	1902
7	7.5	550	200	1520
8	3.0	200	200	1902
9	6.0	450	200	1902
10	3.0	200	200	3818

ILS to runway 13 or 3.0° MLS to runway 31 with missed approach as in the test.
Not tracked.

*The minimum distance to decelerate from 40 KIAS is about 1500 feet. The distances to decelerate for the test was based on the DH for Category I operations. This was the same criteria utilized by Sikorsky in the original tests.

COPTER 354 HELIPORT

ATLANTIC CITY (ACY)

ATLANTIC CITY, NEW JERSEY

ATLANTIC CITY APP CON

124.6 385.5

ATLANTIC CITY TOWER

118.9 239.0

GND CON

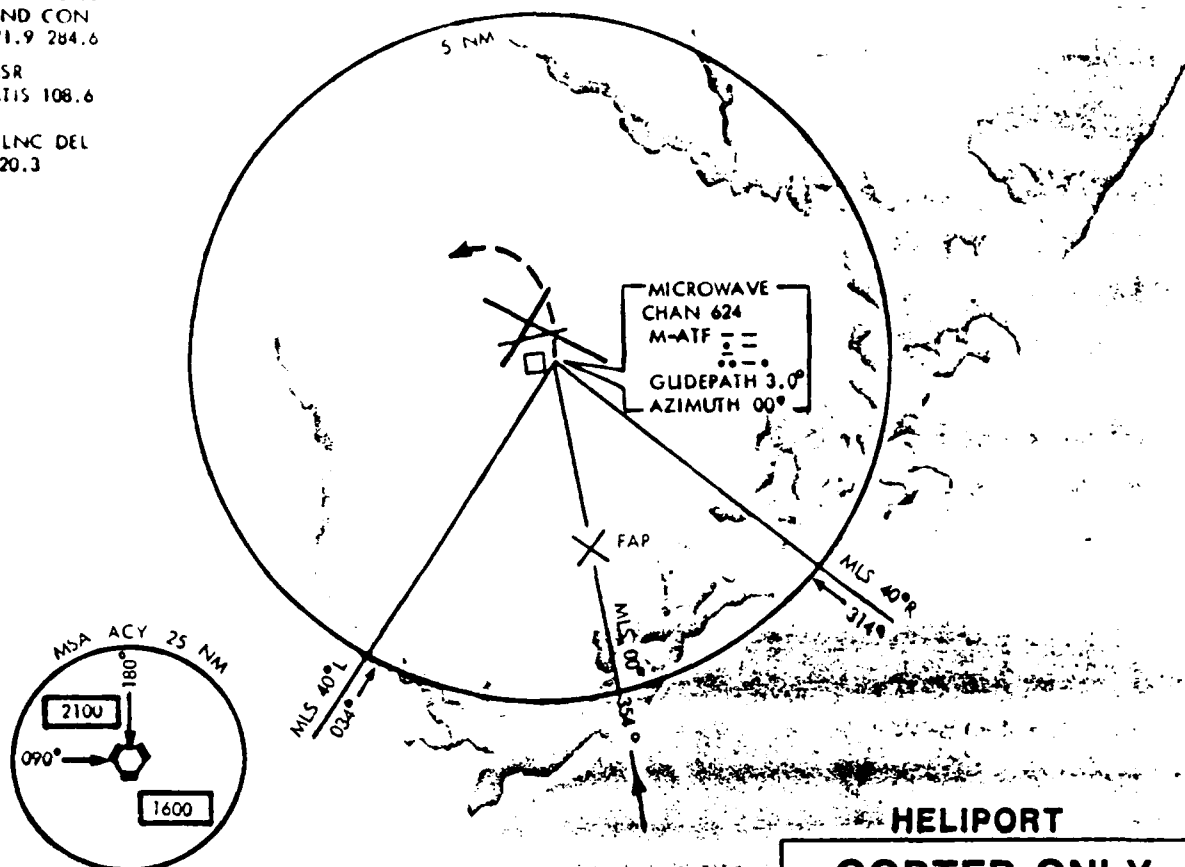
121.9 284.6

ASR

ATIS 108.6

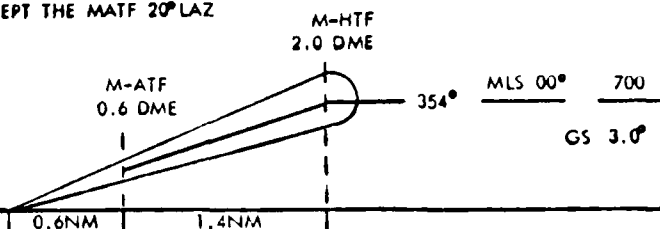
CLNC DEL

120.3



RADAR REQUIRED

MISSED APPROACH : CLIMB STRAIGHT AHEAD TO 500, THEN CLIMBING LEFT TURN HEADING 160° to 1400 to INTERCEPT THE MATF 20° LAZ



CATEGORY	A	H
S-MLS 354°	262-1/2 200 (200-1/2)	N/A
S-AZ 354°	420-3/4 358(400-3/4)	N/A

HELIPAD LOCATED 135 FT. LEFT OF COURSE

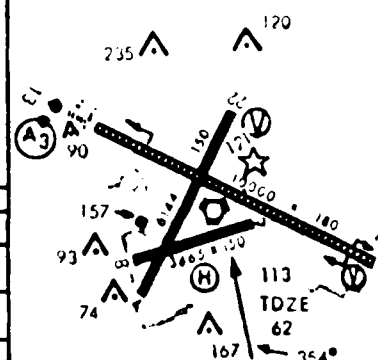
TERPS TEST ONLY

RATE OF DESCENT 395 FT/MIN AT 75 KNOTS

HELIPORT

COPTER ONLY

ELEV 76



TDZ/CL Rwy 13 and 31
MIRL Rwy 4-22 and 13-31
MIRL Rwy 8-26

FAF TO MAP 2.0 N.M.

Knots	50	60	70	80	90
Min Sec	2 24	2 00	1 43	1 30	1 20

COPTER

39°27'N-74°35'W

ATLANTIC CITY, NEW JERSEY
ATLANTIC CITY (ACY)

1. ELEVATION ANGLE 11.5° ELEVATION ANGLE 11.5° ELEVATION ANGLE 11.5°

COPTER

354 HELIPORT

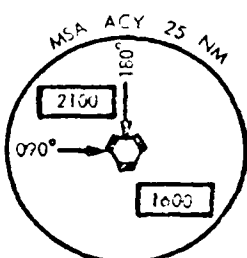
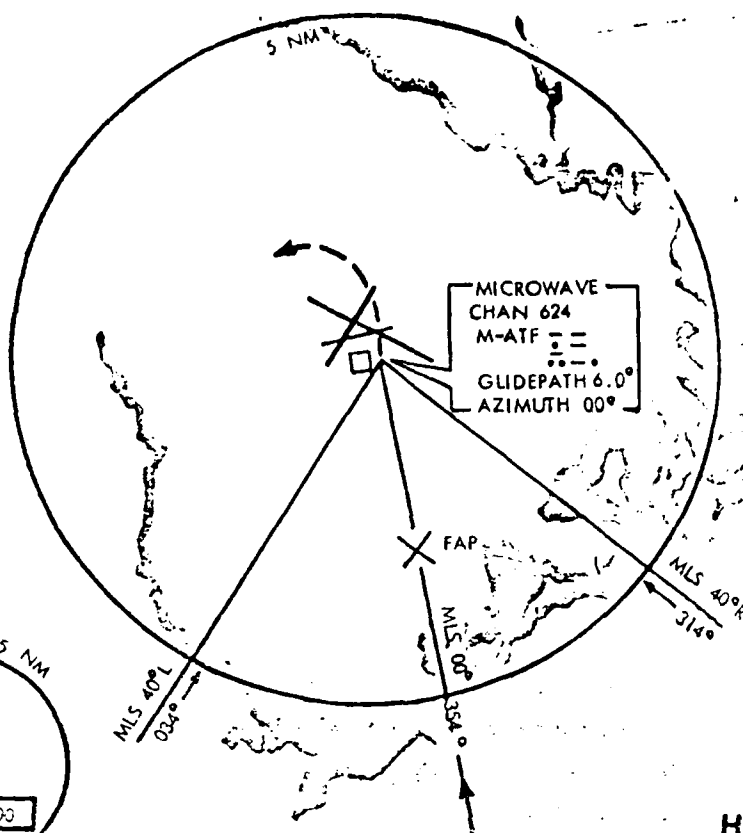
ATLANTIC CITY (ACY)

ATLANTIC CITY, NEW JERSEY

ATLANTIC CITY APP CON
124.6 385.5
ATLANTIC CITY TOWER
118.9 239.0
GND CON
121.9 284.6

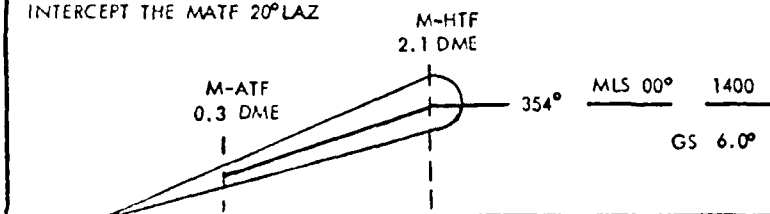
ASR
ATIS 108.6

CLNC DEL
120.3



RADAR REQUIRED

MISSED APPROACH : CLIMB STRAIGHT AHEAD TO 500, THEN CLIMBING LEFT TURN HEADING 160° to 1400 to INTERCEPT THE MATF 20° LAZ



CATEGORY	A	H
S-MLS 354°	262-1/2 200 (200-1/2)	N/A
S-AZ 354°	420-3/4 353(400-3/4)	N/A

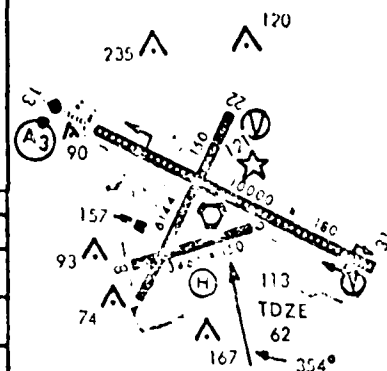
HELIPAD LOCATED 135 FT. LEFT OF COURSE
TERFS TEST ONLY

RATE OF DESCENT 700 FT/MIN AT 25 KNOTS

HELIPORT

COPTER ONLY

ELEV 76



TDZ/CL Rwy 13 and 31
HRL Rlys 4-22 and 13-31
MRL Rwy 8-26

FAP 100 MAP 2.0 NM

Knots	10	20	30	40	50
Min Sec	2:24	2:03	1:43	1:24	1:07

COPTER

39°27'N-74°35'W

ATLANTIC CITY, NEW JERSEY

ATLANTIC CITY (ACY)

FIGURE C. ELEVATION ANGLE MLS COPTER 354 APPROACH

COPTER 354 HELIPORT

ATLANTIC CITY (ACY)

ATLANTIC CITY, NEW JERSEY

ATLANTIC CITY APP CON

124.6 385.5

ATLANTIC CITY TOWER

118.9 239.0

GND CON

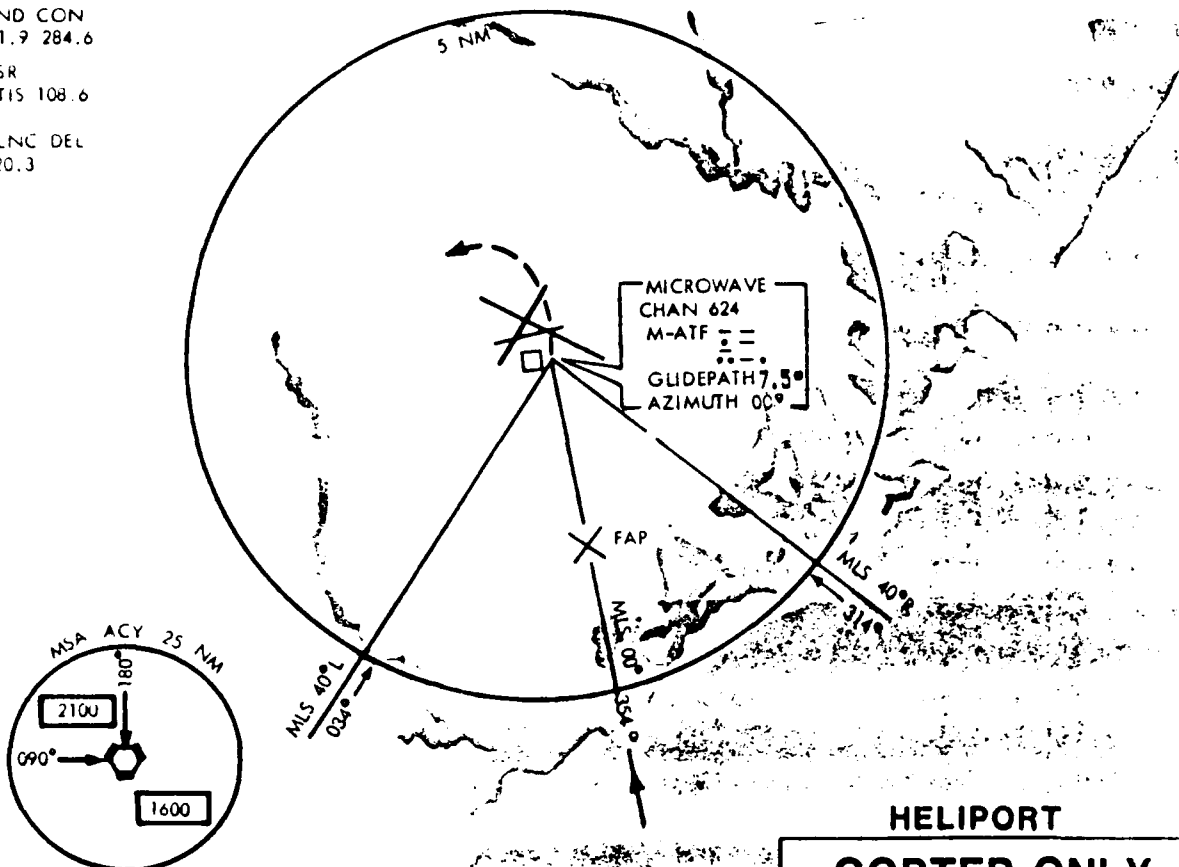
121.9 284.6

ASR

ATIS 108.6

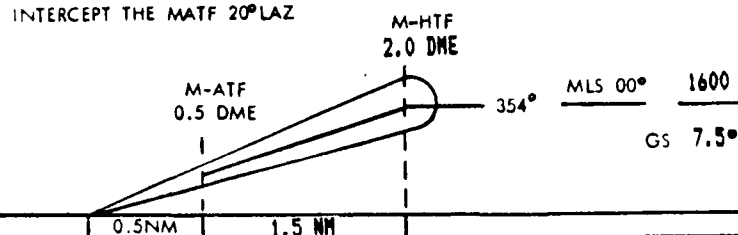
CLNC DEL

120.3



RADAR REQUIRED

MISSED APPROACH : CLIMB STRAIGHT AHEAD TO 500, THEN CLIMBING LEFT TURN HEADING 160° to 1400 to INTERCEPT THE MATF 20° LAZ



CATEGORY	A	H
S-MLS 354°	262-1/2 200 (200 - 1/2)	N/A
S-AZ 354°	420-3/4 358(400-3/4)	N/A

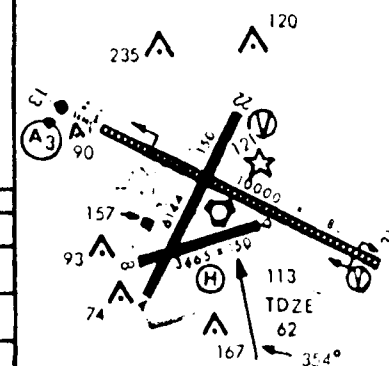
HELIPAD LOCATED 135 FT. LEFT OF COURSE
TERPS TEST ONLY

RATE OF DESCENT 990 FT/MIN AT 75 KNOTS

HELIPORT

COPTER ONLY

ELEV 76



TDZ/CL Rwy 13 and 31
HIRL Rwy 4-22 and 13-31
MIRL Rwy 8-26

FAF TO MAP 2.0 NM

Knots	50	60	70	80	90
Min Sec	2:24	2:00	1:43	1:30	1:20

COPTER

39°27'N-74°35'W

ATLANTIC CITY, NEW JERSEY
ATLANTIC CITY (ACY)

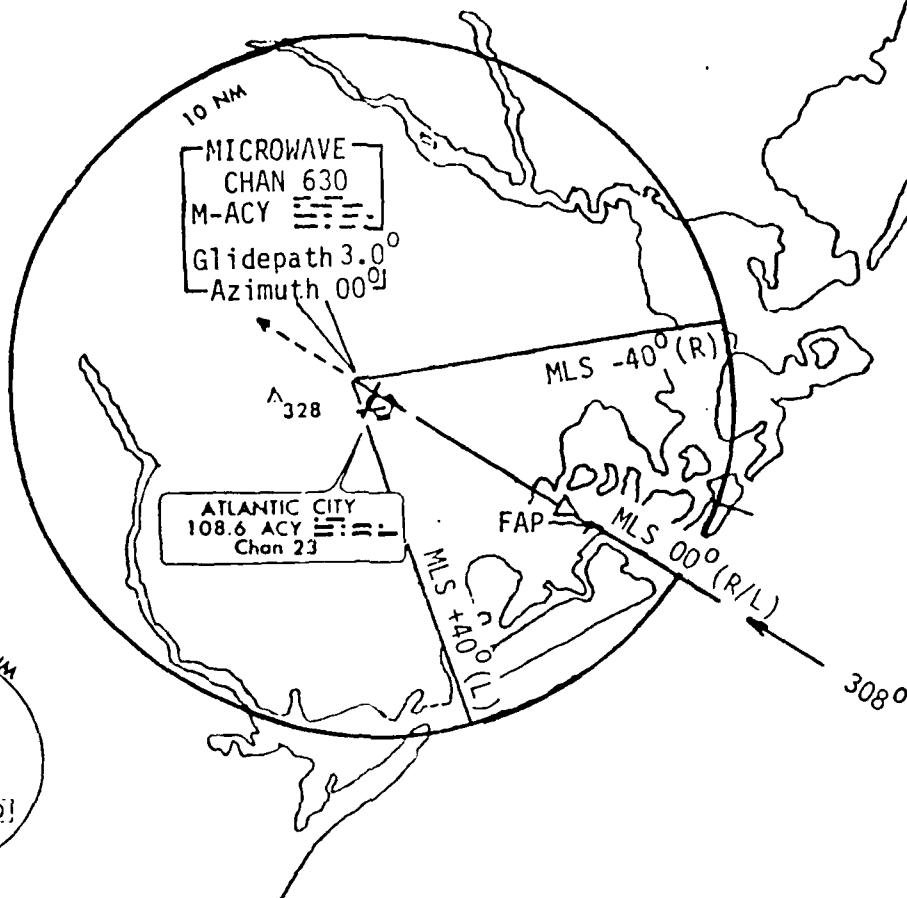
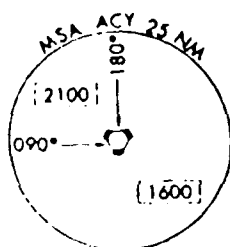
FIGURE 7. 7.5° ELEVATION AVIATION MLS COPTER 354 APPROACH

MLS RWY 31

ATLANTIC CITY(ACY)
ATLANTIC CITY, NEW JERSEY

ATLANTIC CITY APP CON
124.6 385.5
ATLANTIC CITY TOWER
118.9 239.0
GND CON
121.9 284.6
CLNC DEL
127.85
★SR
ATIS 108.6

△
589



Missed Approach: Climb
Heading 308° to 1500 feet
for radar vectors.

M-ACY
5.6 DME

M-ACY
2.2 DME

1350

1400

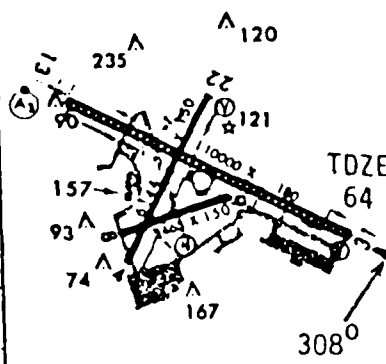
308°
MLS 00°(R/L)
GS 3.0°
TCH 55

CATEGORY	A	B	C	D	E
S-MLS 31	264-1/2	200	(200-1/2)		

▽
△

MLS TEST VFR ONLY

ELEV 76



TDZ/CL Rwy 13
HIRL Rwy 4-22 and 13-31

39°27'N - 74°35'W

ATLANTIC CITY, NEW JERSEY
ATLANTIC CITY(ACY)

FIGURE 8. RUNWAY 31 MLS APPROACH

Altitudes for intercepting the elevation were:

3° EL - 700 feet
6° EL - 1400 feet
7.5° EL - 1600 feet

Each approach was flown to a DH of 200 feet. The deceleration distances from DH to touchdown are shown in table 3.

TABLE 3. DH TO TOUCHDOWN DECELERATION DISTANCES

<u>EL Angle</u>	<u>Distance</u>
3°	3818 feet or 0.6 nmi
6°	1902 feet or 0.3 nmi
7.5°	1520 feet or 0.25 nmi

In the certification heliport MLS testing at Battery Park (appendix C), it was recommended to approve MLS heliport approaches as a two-pilot procedure. In this test the crew composition consisted of two pilots. The duties of the copilot were:

1. Performing necessary radio communications.
2. Reading checklists.
3. Clearing all turns.
4. Calling out altitudes +500 feet and +100 from assigned or desired altitudes.
5. Setting avionics equipment for the approach.
6. Calling the deceleration point 2.5 DME from the heliport.
7. Announcing go around at DH.
8. Flying the aircraft after the level off at 1600 feet on the missed approach.

Airspeed while on downwind was maintained at between 90 to 120 KIAS. Before reaching the 4 nmi DME fix outbound, while the pilot was setting the instruments for the approach, the copilot leveled off at the desired altitude for the approach. A turn to a heading of 045° was performed to intercept the inbound course one mile prior to the deceleration point (3.5 nmi DME). Once established on the inbound course, the subject began to decelerate so as to be stabilized at 40 KIAS at the deceleration point (2.5 nmi DME). This speed was maintained throughout the approach to DH. Once established on the approach,

the AZ was maintained with the cyclic while the EL was maintained with the collective, using the "backside" of the power curve approach techniques. At DH, which was 200 feet radar altitude, the pilot initiated a missed approach.

After leveling the aircraft at 1600 feet m.s.l. on the missed approach, the safety pilot took over the controls while the subject responded to the approach evaluation conducted by the data collection technician. The pilot was hooded to simulate instrument meteorological conditions during the entire approach and missed approach segments. Following each run the subject was asked to rate the approach to DH and the missed approach according to the Cooper Harper rating scale.

The subjects flew three approaches to a DH of 200 feet, at each of the EL angles 3°, 6°, and 7.5°.

DATA REDUCTION

Various aircraft performance data are obtained from sensors onboard the aircraft and recorded on magnetic tape. The data collected are divided into two groups. Aircraft state parameters: such as IAS, true airspeed (TAS), pitch, roll, and yaw attitudes, vertical speed and magnetic heading, and control movement. MLS parameters: received raw AZ and EL angles, DME range, displayed AZ and EL angles, and MLS signal flags. A list of the parameters collected is contained in table 4.

Data collection started at the 4-nmi DME range inbound on the approach. Collection terminated when the aircraft had climbed through 1600 feet altitude on the missed approach. Events were marked manually by the data collection technician at 4 DME inbound, EL angle intercept, DH, 500 feet radar altitude on the missed approach and 1600 feet MSL on the missed approach.

Ground tracking (laser and extended area radar) data and airborne data were merged and utilized to generate plots depicting both plan and profile views of each procedure relative to the desired course (figures 9 and 10).

The data collection technician was responsible for maintenance of the airborne flight log. This log provided the collection of subject and test pilot comments in real time. Observer logs and pilot evaluations were analyzed for overall trends.

FLIGHT TEST ANALYSIS

Three pilots participated in the project. Below is a listing of the pilots experience level and ratings:

Pilot 1

Commercial/Instrument Rotorcraft-Helicopter
400 hours total helicopter time
20 hours in the last 6 months
60 hours actual/simulated instrument time

TABLE 4. AIRBORNE DATA COLLECTION SPECIFICATIONS

<u>Parameter</u>	<u>Units</u>	<u>Sample Rate (Hz)</u>	<u>Resolution</u>
Time	Hours/minutes/seconds	N/A	0.001 second
ADC Indicated Airspeed	knots	2	1 knot
ADC Vertical Velocity	Feet/seconds	2	10 ft/min
Aircraft Heading	Degrees/magnetic	2	0.020
Barometric Altitude 29.92	Feet	2	2 feet
Radar Altitude	Feet	2	1.2 feet
Vertical Deviation Subject Pilot HSI	Linear: feet Dots: as scaled on display Angular: degrees	2	0.001 dots
Lateral Deviation Subject Pilot HSI	Angular: degrees		
MLS Azimuth	Degrees	2	0.005
MLS Elevation	Degrees	2	0.005
MLS Range	Feet	2	4 ft
Along Track Distance	Feet	2	4 ft
MLS Flags			
Cycle Position	Percent of full scale	2	0.05%
Pedal Position	Percent of full scale	2	0.05%
Collective Position	Percent of full scale	2	0.05%
Roll Angle	Degrees	2	0.02%
Pitch Angle	Degrees	2	0.02%
Event Marker	Discrete code	2	
Normal Acceleration	g's	20	0.01g

Note: ADC = Air Data Computer

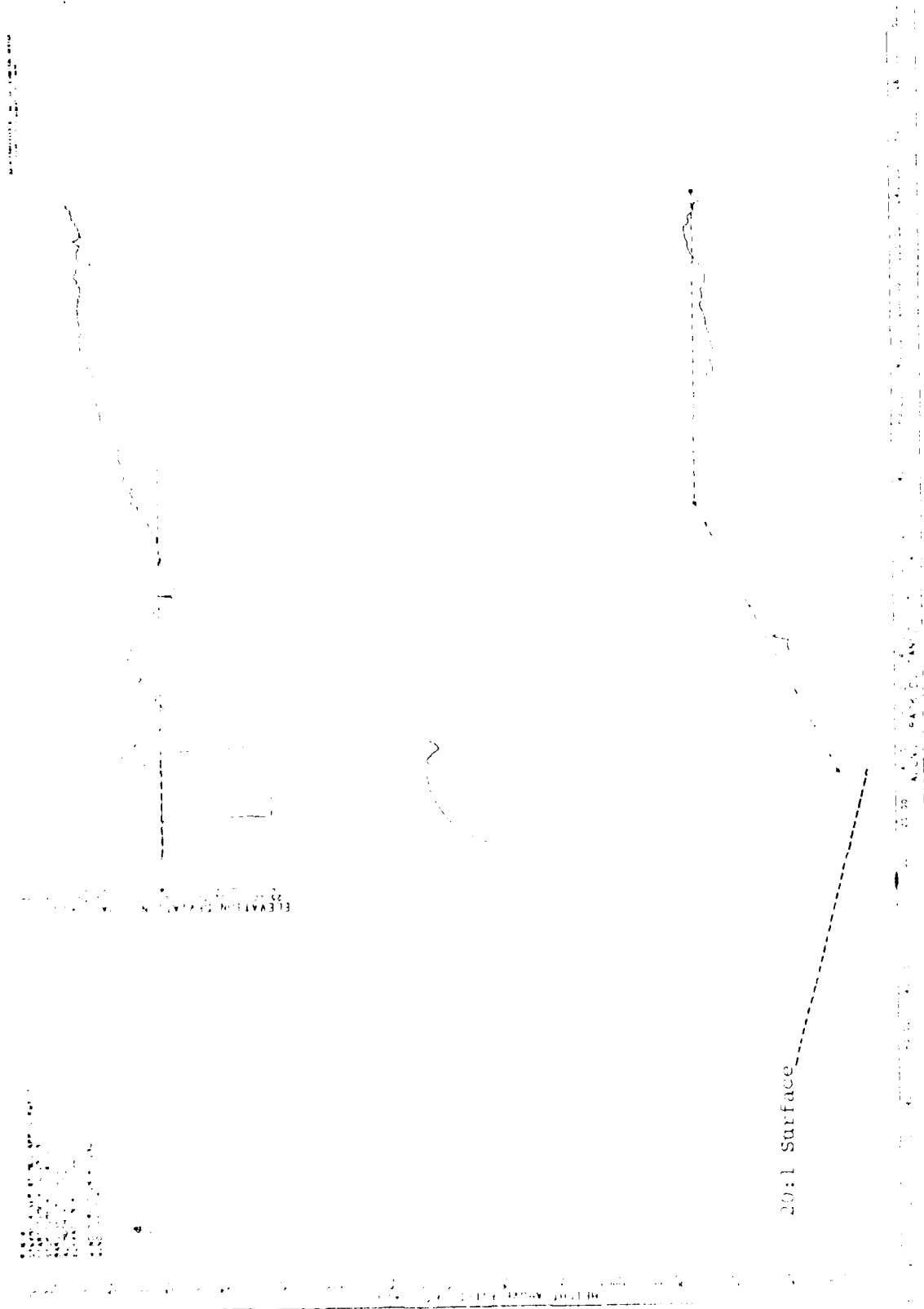


FIGURE 9. PROFILE VIEW

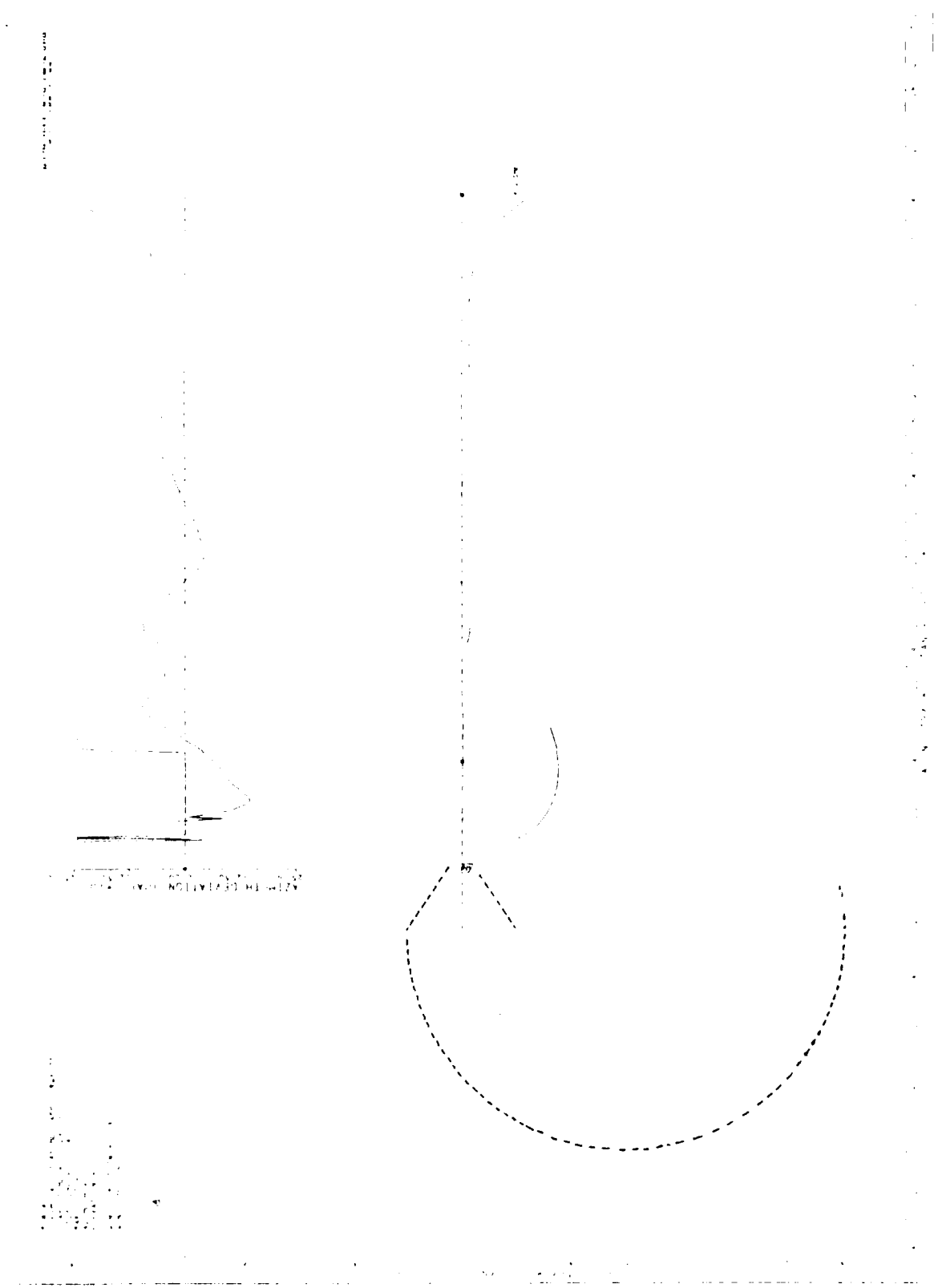


FIGURE 10. PLAN VIEW

Pilot 2

Airline Transport Pilot Rotorcraft-Helicopter
2000 hours total helicopter time
50 hours in the last 6 months
300 hours actual/simulated instrument time

Pilot 3

Airline Transport Pilot Rotorcraft-Helicopter
3000 hours total helicopter time
50 hours in the last 6 months
500 hours actual/simulated instrument time

The flight control system (SHZ-760) was very different than the SPZ-7000 DDAFCS used in the certification flights in New York. Only one of the subjects rated the approaches as flown in our aircraft acceptable for IFR use. The other subjects rated the approach phase as needing improvement because workload levels in maintaining heading, airspeed, and course alignment were too high. These two pilots did not feel that any of the approaches would be acceptable to fly in IMC conditions. Two improvements to the procedures identified in the test plan resulted in a reduction in perceived workload. They were:

1. Use the airspeed hold coupled to assist in pitch control. Of all axes to control, pitch was considered by all the subjects to be the most difficult. By using the airspeed hold function of the flight director coupled to the flight control system, the pilots felt they reduced the workload greatly.
2. Having the copilot control the heading by use of his tail rotor pedals also greatly reduced the perceived workload on the pilot flying the approach. Without the Sperry SPZ-7000 4-axis flight control system with heading hold, copilot assistance in heading control would reduce pilot workload in maintaining an approach azimuth.

Wind limitations used for the test were a maximum tailwind and crosswind of 15 knots. The same limits were used in the certification tests. The weather was better than 5000 foot ceiling and 5 miles visibility for the data collection flights. The winds averaged 289° at 12 knots, which yielded an average 10-knot direct crosswind component. With crosswind components greater than this, pilot comments indicated that the "sideslip" technique for flying the azimuth at low speeds became very uncomfortable.

CONCLUSIONS

The main purpose of the flight test was to provide ASW-110 composite flight path plots of aircraft track from the decision height (DH) through the missed approach segments. These plots were used to determine if any current terminal instrument procedures (TERPS) criteria would be violated by reducing minimum instrument meteorological conditions airspeed (V_{min}) to 40 knots indicated

airspeed (KIAS). To this end the plots indicate that there were no penetrations of the 20:1 missed approach surface (see appendix E). Figure 11 shows the HL data for the three approach angles flown.

The maximum deviation allowed by TERPS for the height loss (HL) at missed approach rises along a 20:1 plane which begins at the surface or 250 feet below the missed approach point. For this test that means that the 20:1 obstacle free surface begins at ground level. At most, only a 40-foot fly under at DH was detected during the 24 missed approaches flown. Additionally, from the questionnaire results, the subject pilots felt that the transition from the approaches to the missed approaches were very easy. The ease in flying the missed approach is due mainly to the decreased rate of descent on each of the approaches.

RECOMMENDATIONS

1. Altitude loss at decision height (DH) was considerably less than altitude loss which has been measured at higher approach speeds. Pilots felt transition to the missed approach segment could easily be accomplished with a 40-knot approach speed. To be able to provide conclusive statistics on the missed approach phase, a much larger pilot sample would be required. The sample should consist of 12 subject pilots replicating each of the three approach profiles three times. This would result in nine approaches per subject.
2. Ideally, this flight test should be conducted in an approved SPZ-7000 aircraft configuration. If this cannot be accomplished, then it is requested that ASW-110 assist ACT-140 in determining what has to be done to satisfactorily emulate an SPZ-7000 automatic flight control system (AFCS) in S-76A registry number N-38.
3. A flight test should be performed at the Technical Center evaluating 2 cue vs 3 cue flight directors for microwave landing system (MLS) steep angle approaches to heliports. This study would provide ASW-110 with potential uses of flight directors for reducing pilot workload when flying steep angle approaches to heliports. This could also provide ASW-110 with a data base to make certification decisions as to benefits or restrictions of the majority of systems currently in use by the majority of the helicopter population. This test would identify any operational 2 cue benefits for steep angle approaches.

REFERENCES

1. Single Pilot IFR System Pilot's Manual for the S-76. Sperry Flight Systems, Avionics Division.
2. Luciani, V. J., NAFEC Range Instrumentation System, FAA-NA-74-32, May 1975.
3. Enias, J., Webb, M., and Billmann, B., Battery Park Heliport Flight Test Results, DOT/FAA/CT-TN85/58, December 1985.

HEIGHT LOSS DATA MEAN/STD.DEV.

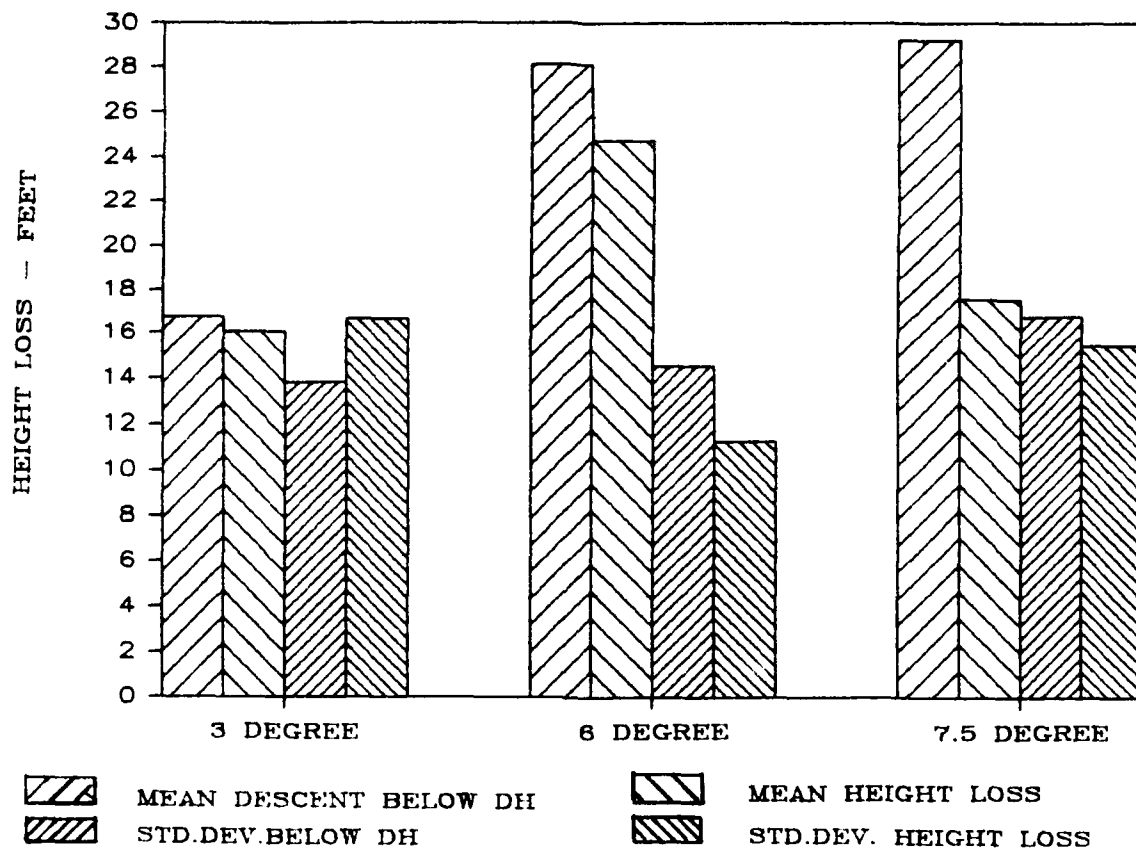


FIGURE 11. HEIGHT LOSS DATA MEAN AND STANDARD DEVIATION

APPENDIX A
LOW SPEED IFR APPROACHES FOR HELICOPTERS



US Department
of Transportation
**Federal Aviation
Administration**

Memorandum

Subject: Low Speed IFR Approaches for Helicopters

Date: MAY 20 1985

From:

Don P. Watson

Reply to
Att: 01

Don P. Watson
Manager, Aircraft Certification Division, ASW-100

To:

ANE-150

This is in response to ANE-150's subject letter dated April 24, 1985.

The following guidance should be used to evaluate and approve transport category helicopter approach, landing, and missed approach procedures using airspeeds below V_{MINI} until such time as further regulatory actions are completed. This guidance may be modified as a result of the S-76 evaluation conducted by ASW-110 and ANE-150 representatives.

In addition to the requirements of Appendix B, Part 29, the following shall be required.

- a. Airspeeds below V_{MINI} may be used only during approach, landing, and missed approach procedures.
- b. During a missed approach, the helicopter must be safely controllable and maneuverable while accelerating from the minimum approved approach speed to V_{YI} while using not less than maximum continuous power.
- c. Static longitudinal stability. For approach airspeeds below V_{MINI} , the longitudinal control position and force versus speed curves must not have a negative slope within a range of airspeeds ± 5 knots either side of any airspeeds between V_{MINI} and the higher of 25 knots or the minimum approved approach speed, with--
 - (1) The helicopter trimmed at V_{MINI} and the higher of 25 knots or the minimum approved approach speed;
 - (2) Power required to maintain a 3° glideslope and to maintain the steepest approach gradient for which approval is requested; and
 - (3) Landing gear extended, if applicable.
 - (4) A return to trim airspeed is not required at airspeeds below V_{MINI} .
- d. Dynamic stability for approach speeds below V_{MINI} :

(1) Any oscillation having a period of less than 5 seconds must damp to one-half amplitude in not more than two cycles.

(2) Any oscillation having a period of 5 seconds or more but less than 10 seconds must be damped.

(3) Any oscillation having a period of 10 seconds or more, or any aperiodic response, may not achieve double amplitude in less than 10 seconds.

e. The need for additional equipment, systems, and installations should be evaluated.

The following background information is provided for the FAA representatives to consider during their evaluation:

a. The requirement for a radar altimeter. FAA/NASA studies have indicated this equipment and systems are necessary during approaches at speeds below V_{MINI}. Helicopters using approach speeds below V_{MINI} will, in most cases, use approach gradients (glideslopes) steeper than the normal 3° ILS glideslope. A 6° gradient was used during most of the FAA/NASA studies. Even at low or decelerating approach speeds, the steeper gradients result in a relatively high rate of descent at decision heights (and assumed breakout from IMC to VMC). The pilot will accept these higher rates of descent with a radio altimeter, but some concern was expressed by some of the pilots during the FAA/NASA studies if a radio altimeter was not available. Significant advantages were also found when the radio altimeter was used for annunciation of decision height.

b. The requirement to provide display(s) which provide the relationship of speed, position, and landing area. FAA/NASA studies have indicated that it may be necessary to provide a display of progress of speed, position, and landing area. The low approach speeds greatly amplify the effect of any wind and, as the windspeed nears the approach airspeed, the groundspeed of the helicopter may become so low that the rate of closure to the landing site is unacceptably low.

The relative direction of the wind to the helicopter and desired approach path may also induce significant tracking problems. The helicopter pilot desires a display that shows his relative position to the landing site and the rate of closure to the landing site such as that visually perceived during a visual approach. As a minimum, a distance measuring equipment (DME) system, in conjunction with the ILS/MLS, would fulfill this requirement; however, since this requires the busy pilot to mentally

integrate the DME display to determine closure rate, the objective of the requirement is meant to be an incentive for new systems nearer to meeting the desires of the pilot. The addition of a groundspeed readout display would be preferred over a normal DME display only.

c. Airspeed systems. An airspeed system that provides repeatable information is necessary for control during low speed final approach segment. The accuracy and calibration requirements of Part 29 are not changed. Precise or accurate airspeed information is much less a requirement than repeatable airspeed information. Satisfactory procedures and control can be readily developed and used with a repeatable airspeed indication. Translational lift has a significant effect on pitot-static airspeed systems; however, proper design permits steady and repeatable indications when decelerating to translational lift airspeed. This requirement does not exclude the use of nonpitot-static airspeed systems but is not intended to require them.

d. Flight control guidance system. FAA/NASA studies have indicated that a flight control guidance system that consists of either an automatic approach coupler or a flight director system may be required. With approach speeds below about 50 knots, the tracking task becomes difficult because any wind or turbulence is a larger percentage of the airspeed. Besides the physical relationship (i.e., groundspeed vs. airspeed vs. aerodynamics) that a wind will generate, the pilot must "learn" that large corrections are required. A simple example of the difficulty of the approach can be envisioned where a crosswind velocity equals the forward velocity of the helicopter. In this case, the required correction to stay on the localizer centerline is 90° and, of course, the helicopter would never get to the heliport unless some other correction was made. The slow airspeed helps to keep this from being an impossible task, but the integration of the data to provide the right corrections must be made for the pilot, not by the pilot.

Consistent with the FAA commitment to the Rotorcraft Master Plan, the Rotorcraft Certification Directorate considers this new area of instrument flight to be a significant project. Mr. J. S. Honaker, ASW-111, is assigned as Project Officer. Mr. Honaker will plan to attend necessary meetings with Sikorsky as a certification team member and participate in FAA test flights as an observer as agreed during the FAA/Sikorsky meeting on March 29, 1985. We request that you keep Mr. Honaker advised of the project schedule.

APPENDIX B
ACT-140 LETTER: EVALUATION OF SIKORSKY S-76
HELICOPTER FOR PRECISION APPROACHES (MLS AND ILS)
AT AIRSPEED BELOW EXISTING V_{mini}

INFORMATION: Evaluation of Sikorsky S-76 Helicopter
for Precision Approaches (MLS and ILS) at Airspeeds
Below Existing V_{mini}

ORIGINAL SIGNED BY

James Enias
Flight Operations Analyst, ACT-140

Thru: Helicopter Program Manager, AFM-720
Helicopter Technical Program Manager, ACT-140

The purpose of this memorandum is to identify the requirement for a "quick-look" flight test activity to explore the operational characteristics of a lower V_{mini} during precision approach and missed approach operations to a helipad.

As you are aware, UIC Sikorsky, Paul Balfe (AME-150), Paul Paidley (ASW-270), and Eric Bries (ASW-110) have recently completed an evaluation of the S-76 helicopter for precision approaches (MLS and ILS) at airspeeds below the existing V_{mini} of 60 KIAS. It appears from the trip report completed by ASW-110 (attachment) that Sikorsky will request certification for a 40 KIAS V_{mini} to a DA of 200 feet for glidepath angles up to 7.5°.

There is no doubt in my mind that these numbers are feasible, however, there may be some impact on TERPS during a missed approach. Of concern is the time, distance and altitude loss, if any, inherent with accelerating from DA at 40 KTS may be significantly different than the profile from DA at 60 KTS. Too, the 40 KTS profile may penetrate the existing or planned TERPS missed approach surface. This perceived difference would result from the fact that when executing a missed approach from a speed below V_{toss} ; first increase collective to obtain takeoff torque and then, albeit simultaneous, accelerate forward to 52 KIAS (V_{toss}) before attempting to establish a positive rate of climb.

I have discussed this matter with Eric Bries and we feel that a quick-look flight test would demonstrate a trend, if any, associated with procedures at the lower V_{mini} . We feel this information would be of benefit to both support certification issues, and substantiate any TERPS-related issues.

As planned, this test would consist of 8 approaches/missed approaches to a D_H of 200 feet at each of the elevation angles of 3°, 6°, and 7.5°. These approaches would be flown by FAA pilots using raw data guidance information and within the equipment/guidelines contained in attachment 1. This activity could be completed during October with approximately 6 hours of flight time in the S-70, and we would provide the resultant data consistent with previous helicopter TERPS flight tests. Please note that our V_{min} work was originally scheduled for January 1986, but is being accelerated due to the expressed interest from ASW-110.

If there are any questions or comments concerning this matter, please contact me at HHS 402-6300. If you are in agreement with this proposed flight test activity, please see to it that AWP-210 provides a formal request, together with any required additions/changes to this office.

Attachment

f

ACF-140:JHLLIS:x6800:d1b:6/20/85:(GARR):0150L

APPENDIX C
ASW-110 LETTER: EVALUATION OF SIKORSKY S-76
HELICOPTER FOR PRECISION APPROACHES (MLS AND ILS)
AT AIRSPEED BELOW EXISTING V_{mini}



U.S. Department
of Transportation

Federal Aviation
Administration

Memorandum

INFORMATION: Evaluation of the Sikorsky S-76A Helicopter
for Precision Instrument Approaches Using Final approach
Airspeeds Below V_{mini}

SEP 6 1985

Ronald L. Vavruska
Ronald L. Vavruska

Manager, Boston Aircraft Certification Office, ANE-150

Manager, Helicopter and Policy Procedures Staff, ASW-110

Sikorsky Aircraft requested FAA certification criteria and policy for IFR approaches at final approach airspeeds below V_{mini} in Sikorsky letter CAL-85-8500 dated April 2, 1985. The Rotorcraft Certification Directorate provided guidance for evaluating the low speed IFR approaches in a letter to ANE-150 dated May 20, 1985. An evaluation of the low airspeed final approaches was flown by Mr. Paul J. Balfe, ANE-156, during the period May 21 through 31, 1985. The attached report covers the results of this test program.

We believe the Sikorsky S-76A equipped with the Sperry SPZ-7000 DDAFCS operating in the ATT mode demonstrated acceptable flight characteristics during instrument final approaches using airspeeds between V_{mini} and 40 KIAS with the following limitations:

1. A minimum crew of two helicopter instrument rated pilots.
2. A minimum approach airspeed of 40 KIAS.
3. A maximum crosswind component of 15 knots.
4. The maximum glideslope is 7.5 degrees.
5. A suitable groundspeed indicator must be available (DME/P, DME, LORAN C, RNAV, etc.).
6. A suitable indication of the deceleration point prior to glidepath interception (DME, VOR radial, NDB, MB, etc.).
7. Installation of approved instrument precision approach receiver equipment (ILS, MLS).
8. An approved instruction manual (RFM supplement, etc.) must be available.
9. The Sperry SPZ-7000 flight director may be used in the 3 cue mode, but may not be coupled to the AFCS. Coupled AFCS (automatic pilot) approaches below V_{mini} are not authorized. Flight director 2 cue (azimuth and glidepath) approaches are not authorized at airspeeds below V_{mini} .

This configuration also demonstrated compliance with the guidance provided by the Rotorcraft Certification Directorate. With your concurrence, we will certificate the Sikorsky S-76A with the listed limitations for precision instrument final approaches using airspeeds between V_{mini} and 40 KIAS.

The guidance developed by the Rotorcraft Certification Directorate provided a helicopter with acceptable flying qualities for low airspeed precision instrument approaches. We recommend this material be formalized in the certification requirements for helicopter instrument flight.

Attachment

APPENDIX D
ADVANCES IN DECELERATING STEEP APPROACH AND LANDING
FOR HELICOPTER INSTRUMENT APPROACHES

Advances in Decelerating Steep Approach
and Landing for Helicopter Instrument Approaches

Paul S. Demko
Electronics Project Engineer
and
CPT James H. Boschma
R&D Technical Operations Officer
USA Avionics R&D Activity

PRESENTED AT THE 35th ANNUAL NATIONAL FORUM
OF THE
AMERICAN HELICOPTER SOCIETY
WASHINGTON, D.C.
MAY 1979

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1325 18th STREET, N.W.
WASHINGTON, D.C. 20036



PREPRINT NO. 79-16

Advances in Decelerating Steep Approach
and Landing for Helicopter Instrument Approaches

Paul S. Demko
Electronics Project Engineer
and
CPT James H. Boschma
R&D Technical Operations Officer
USA Avionics R&D Activity

Abstract

A true, total operational capability for helicopters during instrument meteorological conditions (IMC) and, in many cases, during night flying conditions will not be realized, in practice, until the helicopter pilot is provided the means with which to perform the same decelerating steep approach and landing (DSAL) maneuver during IMC that he routinely performs under visual flying conditions. This means that the helicopter pilot must, in addition to being provided the means with which to safely guide his helicopter along a precise steep angle approach course, be provided the means with which to perform a normal deceleration to a safe approach termination within a confined landing zone. This maneuver must be accomplished without any visual reference to the outside world. Microwave landing guidance systems, complete with the necessary precision DME, working through unique 4-cue/4-axis flight director (FD) and autopilot (AP) systems, have now extended the helicopter's formerly visual DSAL capabilities into the IMC domain. The intent of this paper is to brief the reader on how this capability has been achieved.

This paper describes the instrument decelerating steep approach and landing techniques which were pioneered by the U.S. Army Avionics R&D Activity and expounds on work done by Sperry Flight Systems both independently and under Army contract (see references).

Background

Historically, the helicopter's true Vertical Take-off and Landing (VTOL) capability has been exploitable only under favorable weather conditions: that is, the helicopter pilot could perform a decelerated steep approach and landing to touchdown or hover into a confined landing area only when he could see that landing area from a sufficient distance to perform a comfortable deceleration to a safe stop. Suitable avionics have not existed to extend this capability to operations in instrument weather or at night. The standard procedure under these adverse conditions has been to fly the helicopter in essentially the same manner as fixed-wing aircraft in a fixed-wing Air Traffic Control (ATC) system, performing shallow (30°) glideslope Instrument Landing System (ILS) constant speed approaches to conventional runways. This fixed-wing instrument meteorological condition (IMC) approach to helicopter operations is wasteful of the helicopter's most unique and most valuable capability, its ability to make steep decelerating approaches to a hover into confined landing sites. Under these conditions, this unique utility of the helicopter

is obviously not being used. Furthermore, within today's ATC system, serious traffic conflicts often arise when the slow helicopter competes with the fixed-wing aircraft for the use of the ILS facilities.

The stereotyped fixed-wing operational scenario for the helicopter under IMC should now be changed. The same kind of Decelerated Steep Approach and Landing (DSAL) into confined landing sites which is performed visually can now be performed completely on instruments. Army helicopter flight tests under simulated IMC have clearly demonstrated the safety and practicability of this fact.

The key to the helicopter's ability to perform the DSAL maneuver, under any conditions, is, of course, its ability to decelerate along a precisely defined glideslope and localizer course to a zero forward and vertical velocity with respect to the ground by the time it has reached its touchdown pad.

Two recent AVRADA developments now make the IMC DSAL maneuver feasible. The first of these is an extremely accurate Ku-band landing guidance system which provides precision localizer, glideslope (selectable from 3 through 12 degrees), DME range and DME range rate guidance to the landing aircraft. One particular man-portable model of this system has even been made small enough, less than 40 inches high and 60 pounds, to be carried to almost any site and set up within less than five minutes. The second development is a 4-cue flight director system that, with guidance from that landing system as its primary input, computes control motion or stick position commands for the pilot's cyclic, collective and pedals to accomplish the DSAL maneuver along a precision course to hover or touchdown in the desired LZ. In fact, the maneuver is accomplished automatically, hands-off, when the commands are coupled to the helicopter's 4-axis autopilot system.

The most attractive aspect of the technology described is that it is here today for the user who might be bold enough to desire full utility from his VTOL assets even when the weather does not cooperate.

The Deceleration Maneuver

The prerequisite to any successful helicopter landing is the deceleration maneuver. This fact is, of course, obvious to the helicopter pilot who performs this maneuver in a predictably routine manner every time he makes a VFR approach to a

landing pad. All that needs to be done, then, for helicopter IMC landing, is to extrapolate this deceleration capability into the IMC domain.

The normal helicopter VFR DSAL maneuver is usually initiated at some constant velocity (e.g., 60 knots) and proceeds as such, until at some prescribed distance from the touchdown pad, the pilot executes the deceleration maneuver in order to arrive safely, to a hover or touchdown, at a precise spot within the desired LZ. In VFR weather, the pilot usually determines the point at which he must begin the deceleration from the LZ sight picture and apparent closure rate. This closure rate is sometimes referred to as the constant apparent ground speed and becomes, in reality, the deceleration maneuver. The deceleration usually proceeds at approximately a .05G rate to approach termination. Figure 1 is an illustration of the typical deceleration curve. If the deceleration curve is

CLOSURE RANGE RATE ALONG GLIDESLOPE VERSUS SLANT RANGE TO HOVER OR TOUCHDOWN

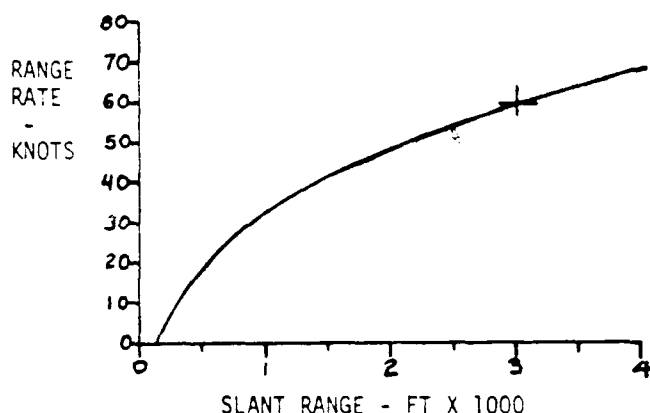


FIGURE 1. Helicopter decelerating Approach profile.

intercepted at 60 knots, the pilot requires about 3000 feet to stop in the normal manner, without exceeding the comfortable deceleration of about .05G.

The deceleration distance remains essentially constant regardless of the approach angle (i.e., glideslope) the pilot has selected; in other words, you still need 3000 feet to stop whether you're flying a 3° approach or a 12° approach if you initiate the deceleration from 60 knots. If this distance is translated into height above touchdown, as in Figure 2, we see immediately that, as the approach angle goes up, so too must the Height Above Touchdown (HAT) at which the pilot MUST HAVE VISUAL CONTACT WITH HIS LZ IF HE HAS NO CAPABILITY TO DECELERATE AND LAND UNDER IMC. We see from Figure 2, for example, if the ability to perform the IMC DSAL maneuver is lacking and a 9° glideslope approach angle is required to get into a particular LZ, then the pilot must have visual contact with his intended LZ at roughly 490 feet HAT.

NOTE 1: DISTANCE TO DECELERATE TO STOP AT .05G
DECELERATION RATE = 3125 FEET FROM 60 KNOTS.

NOTE 2: TIME TO DECELERATE TO STOP AT .05G
DECELERATION RATE = 62.5 SECONDS FROM 60 KNOTS.

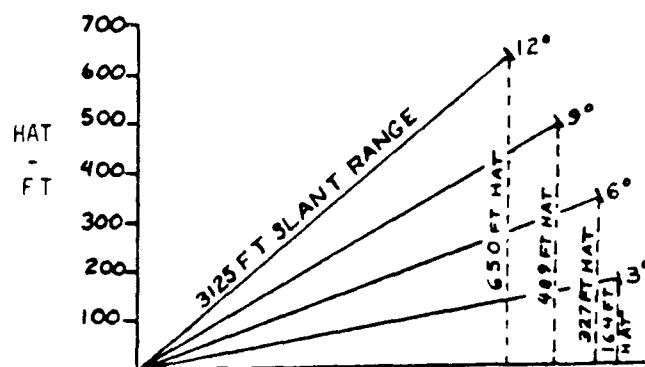


FIGURE 2. Glideslope angle versus height above touchdown required for initiation of decelerating approach to confined landing area.

Lacking the capability to perform the DSAL maneuver under IMC, it is dangerous to think of performing helicopter IMC approaches into confined LZ's to a fixed Decision Height (DH) (e.g., Category II - 100 foot DH). If this is attempted, as the glideslope angle is increased, the distance available for the pilot to decelerate to his landing spot in a LZ is decreased (from the 3000 feet required) while at the same time his vertical velocity at DH and the magnitude of the visual deceleration after breakout is drastically increased. Figure 3 is an illustration of these mutually hazardous effects. For example, from Figure 3, if

HAT VS DECELERATION DISTANCE AND RATE FOR VARYING GLIDESLOPE ANGLE WITH CONSTANT RATE OF DESCENT

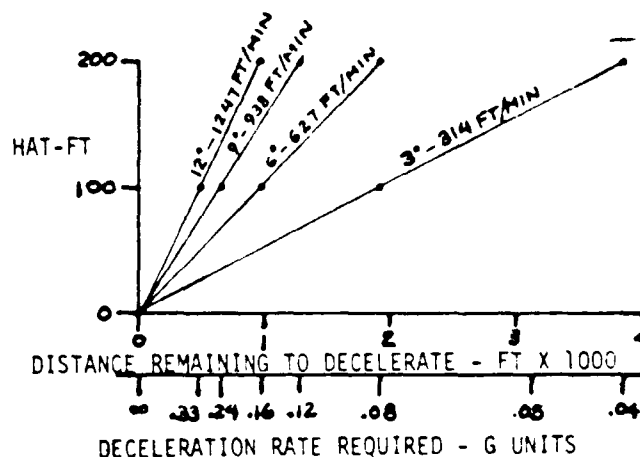


Figure 3. Non-decelerating approach to fixed HAT (60 knot constant speed to HAT).

a pilot attempts to approach to a LZ under IMC at 60 knots along a 9° glideslope and does not expect to achieve visual contact with that LZ until reaching a DH of 100 feet HAT, then he would be left with

only 640 of the 3000 feet he needs to decelerate and land, and be required to perform that deceleration at .24G or 5 times the normal rate. The chances of performing such a maneuver without suffering serious consequences is doubtful. If, on the other hand, the pilot could begin his nominal .05G deceleration while still in IMC at roughly 3000 feet from the LZ, his vertical and forward velocity would be such that, from the point he achieved visual contact with his LZ at 100 feet HAT, he could continue a normal, steep, 90° visual approach to his desired spot in that LZ (see Figure 4). In fact, if he could perform the deceleration

HAT VS DECELERATION DISTANCE AND RANGE RATE FOR VARYING GLIDESLOPE ANGLE WITH DECELERATING RATE OF DESCENT

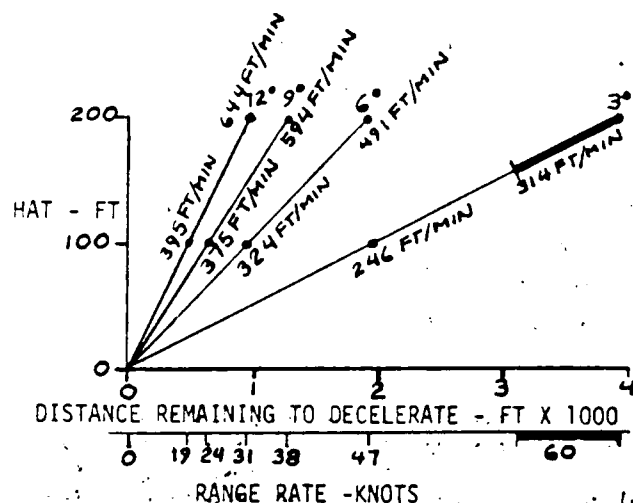
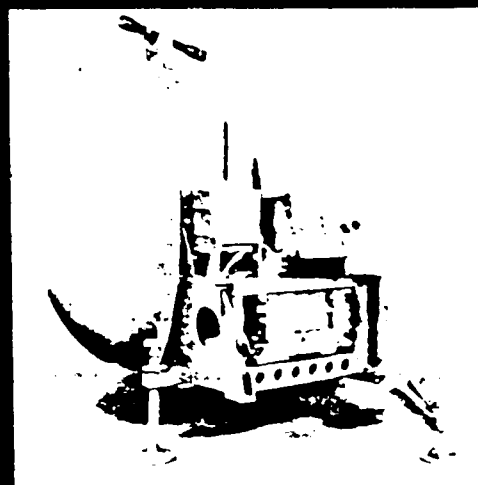


Figure 4. Decelerating approach to fixed HAT (.05G constant deceleration initiated from 60 knots at 3125 ft from touchdown).

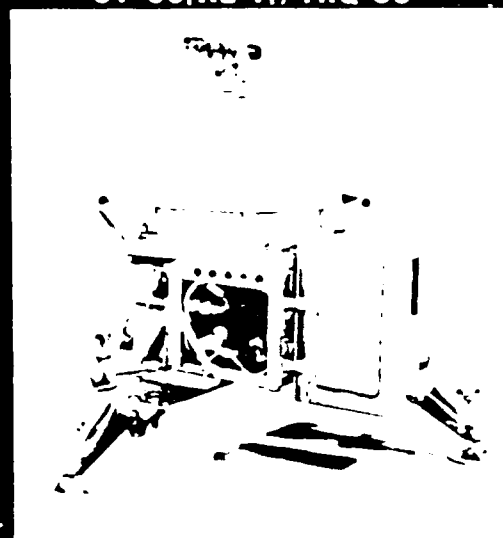
maneuver under IMC, he could, with the proper guidance and display/instrumentation systems, continue the DSAL maneuver to his landing spot safely, without reference to any outside visual cues. The pilot will then have successfully accomplished under IMC what he routinely does in VFR. The implication of a capability such as this is clear: the utility of the helicopter will be enhanced significantly.

The Microwave Landing System

Microwave instrument landing systems, such as the Army's Tactical Landing System (TLS) (Figure 5) and Man Portable Scanning Beam Landing System (MPSBLS) (Figure 6), provide the guidance signals required to perform the DSAL maneuver under IMC. The MPSBLS, for example, is a miniature landing guidance system ground equipment which weighs in (less batteries) at less than 60 pounds, stands about 3 feet tall, encloses a volume of about 2.5 cubic feet and can be moved around easily by one man. In fact, one man can set the system up and have it completely operational in less than 5 minutes. The MPSBLS provides very precise azimuth, elevation, range, range rate and height information (see MPSBLS Equipment Highlights - Table 1) to helicopters on approach when used with the



GLIDESLOPE TRANSMITTER GROUP
OT-65(XE-1)/TRQ-33



DISTANCE MEASURING DECODER-RECEIVER R-1869(XE-1)TRQ-33
LOCALIZER, TRANSMITTER GROUP
OT-64(XE-1)/TRQ-33



AIRBORNE INSTRUMENT LANDING SET
V74-104 AN/ARQ-31(XE-1)

Figure 5. Army Tactical Landing System (TLS).

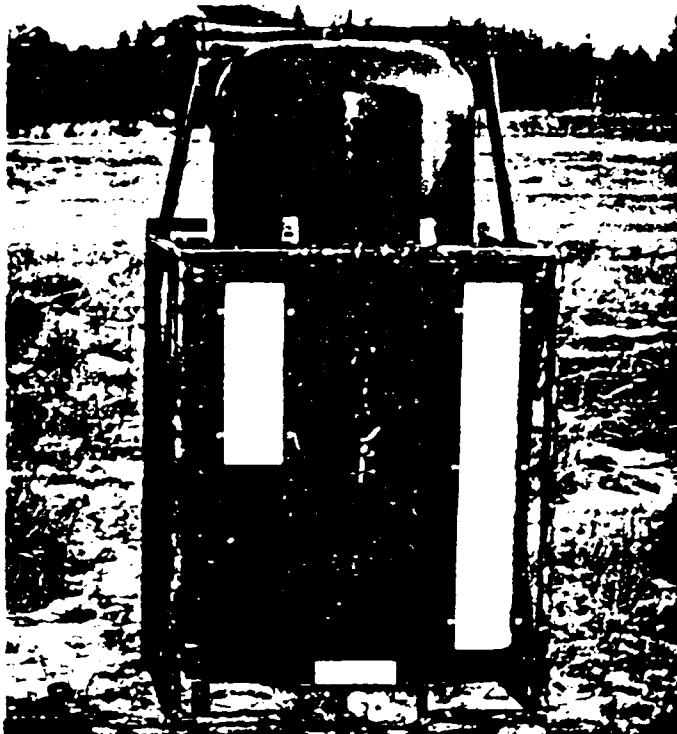


Figure 6. Man Portable Scanning Beam Landing System (MPSBLS).

Instrument Landing Set, Airborne, AN/ARQ-31, which was developed for the Army under the TLS program. The MPSBLS system was designed specifically for helicopter use at glideslopes from 6 through 12 degrees. The required glideslope angle is selected by an "angle" select switch on the AN/ARQ-31 control head located in the aircraft cockpit (see Figure 7).



Figure 7. Control for AN/ARQ-31 Airborne Landing Set.

The landing system operates at Ku-band (azimuth, elevation, range and range rate) and uses scanning beams to generate glideslope and localizer guidance information as does the carrier based Navy AN/SPN-41 and Marine Remote Area Approach and Landing System (MRAALS), used with the AN/ARA-63 and AN/ARN-128 airborne sets. With the MPSBLS/ARQ-31 combination, precise guidance is provided to aircraft all the way to touchdown.

Perhaps the most important guidance data provided to the helicopter, indeed, the guidance data that makes the IMC DSAL maneuver possible, is the range and range rate data derived from the MPSBLS/ARQ-31 Distance Measuring Equipment (DME). The

TABLE 1. MPSBLS Equipment Highlights.

Size (less pedestal):

29.5 in H, 16.5 in W, 16.5 in D.

Weight (including pedestal, less batteries):

59 lbs.

Power consumption:

150 watts total from any 24 VDC source.

Coverage (localizer, glideslope, DME):

$\pm 30^\circ$ in azimuth, 0 to 20° in elevation.

DME error (manufacturer's specification):

50 feet or $\pm 2\%$ of range.

RMS angle error (manufacturer's specification):

0.3° localizer, 0.2° glideslope

Update rate: 4Hz.

No. of channels:

10 (15.412 to 15.688 GHz ground to air).

Antenna beamwidths:

localizer - $6^\circ \times 20^\circ$

glideslope - $4^\circ \times 60^\circ$

DME - $6^\circ \times 20^\circ$

DME range data establishes the exact distance of the helicopter from the touchdown point while the range rate establishes the exact closure rate of the helicopter with respect to the touchdown point. Knowing these two parameters, along with the precise glideslope and localizer parameters, the VFR type deceleration profile can be computed and flown safely to hover and touchdown under zero-zero IMC if, of course, the landing guidance information is properly presented to the pilot. The importance of the DME range and range rate becomes more obvious if one considers that the reliability of pitot-static air data deteriorates rapidly below 40 knots indicated airspeed. Even special low airspeed indicators are of marginal use because they indicate speed relative to the air mass, not relative to the landing point. Speed and distance relative to the desired landing point must be definitively established if the helicopter is to safely land, in IMC, at that point. Precise range and range rate must be provided by a precision landing guidance system.

However, the best quality landing guidance data in the world is of little use to the pilot unless it can be effectively translated into the control movements required to intercept and maintain the required localizer, glideslope and deceleration profiles, which leads us to the DSAL Flight Director.

The DSAL Flight Director

Actual flight test experience has proven that even the most proficient and current instrument pilots cannot be expected to interpret and respond to raw data indications of localizer and glideslope deviations (needle displacements proportional to

the localizer and glideslope deviation angles) along with raw data range and range rate information in the manner required to safely and consistently perform the IMC OSAL maneuver to acceptable landing minimums. The task of performing the IMC OSAL maneuver to speeds slower than 30 knots is further complicated by the fact that the flight dynamics and control responses of the helicopter change drastically as the helicopter decelerates out of the region of translational lift. Therefore, something superior to raw data displays must be made available to the pilot if he is to routinely perform the IMC OSAL maneuver in whatever weather conditions he encounters (including zero ceiling minimums). This "something better" is the 4-Cue FEA Flight Director (FD) system.

The OSAL FD believes the pilot of the necessity of obtaining several raw data instruments, of interpreting the meanings of the raw data indications and of determining what to do with the aircraft in order to maintain a required flight situation. As to the 4-cue FD, raw guidance data, together with air data and instantaneous dynamic and acceleration data relevant to the FD mode all the pilot has selected and programmed, is processed through the FD computer to generate the pilot's left-right (roll), fore-aft (cyclic), pedal and collective control commands necessary to acquire and then maintain the required flight situation.

Before specifically addressing the performance of the IMC OSAL maneuver with the 4-cue FD, it would be beneficial to review the functions of the FD components to which the pilot has access during flight. The pilot selects the vertical (altitude hold or approach), longitudinal (speed hold or deceleration) and lateral (heading, VOR, ADF or localizer) modes he wishes to fly on the "FLIGHT PATH CONTROL" (FPC) which is in the console located between the pilot's and co-pilot's seats (see Figure 3). The modes the pilot has selected are

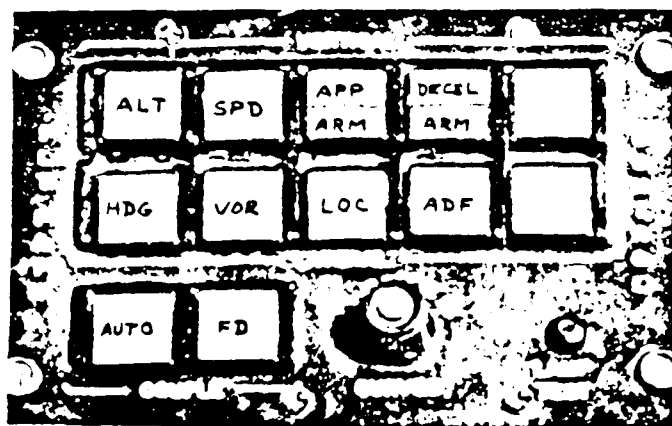


Figure 8. Flight Path Control (FPC) for Flight Director System.

annunciated by lights in the FPC buttons selected and on a "flight director mode annunciator" panel located in the top center of the pilot's primary instrument cluster (see Figures 9 and 10). The pilot selects the course or heading he wishes to fly with the appropriate course select or heading

select knobs on the "horizontal situation indicator" (HSI) (see Figures 9, 10 and 11).

Selected airspeed may be changed through the airspeed "beep" switch on top of the cyclic grip and a go-around or missed approach mode may be activated through a button on the collective grip.

Raw course deviation data is displayed on the HSI along with to/from and heading situation data (see Figure 11). It is important to note that no FD command data is presented on the HSI. The HSI is principally an integration of the cross-pointer course deviation indicator and the radio-magnetic heading indicator and displays only the raw situation data which has not been processed by the FD computer.

The indicator of primary interest to the pilot is the Attitude Director Indicator (ADI) (see Figures 9, 10 and 12). This is the indicator that displays the command data which has been computed by the FD computer and, as such, is an extension of that computer. In reality, the ADI is the link between the FD computer and the pilot's eyes that completes the FD control loop. Therefore, the pilot simply becomes an autopilot servo system and is relieved of the requirement to scan a great many instruments and subsequently figure out what to do with the readings from these instruments. The pilot is simply required to pass along the ADI servo commands to the flight controls.

Four commands are presented to the pilot through the ADI (see Figure 12). The cyclic roll command bar is centered by causing the correct amount of (and rate of) bank through the correct use of his lateral cyclic control. The cyclic roll command bar thus directs the aircraft toward and subsequently causes it to maintain a selected heading or VOR, ADF, TACAN, go-around or localizer course. The cyclic pitch or speed command bar is centered by causing the correct amount of (and rate of) longitudinal pitch angle change through correct use of the fore-aft cyclic control. The cyclic pitch or speed command bar thus directs the aircraft to and causes it to maintain a selected airspeed or to follow the prescribed range rate deceleration profile. The collective (power) command bar is centered when the proper amount of collective (up or down, as required) has been applied by the pilot to control the rate of ascent or descent necessary to climb (or descend) to and maintain a preselected altitude, track a selected glideslope or establish the programmed rate of climb during the go-around or missed approach mode. The Pedal command bar is in view at airspeeds below 45 knots when one of the lateral FD modes is being flown. This bar is centered by applying that amount of pedal required to align the aircraft with either a preselected course (e.g., inbound localizer course) or heading (e.g., go-around heading). When the pedal command bar is in view, priority is devoted to centering it rather than the turn coordination ball. The pedal command bar is especially important on aircraft lacking any sort of independent heading hold mode because, if properly flown, it prevents the aircraft from weathervaning into the

wind at slow speeds and thus prevents a destructive interchange of localizer and glideslope data within the flight path computer (during the terminal phase of a DSAL maneuver), assures adequate lateral control (through the lateral cyclic command) at low speeds and, perhaps most importantly, assures the pilot that he only needs to look straight ahead to find the landing zone when he transitions from IMC to VFR flying conditions.

Additional data presented on the ADI include the artificial horizon, height above touchdown, turn coordination inclinometer (or turn ball - used by the pilot for turn coordination when the pedal command bar is out of view) and raw data glideslope deviation (in view and active when approach arm or approach mode is in use). Therefore, all essential command and critical situation data (e.g., aircraft attitude) are presented in one place for the pilot to view.

Now that the various DSAL FD functions have been introduced, we are prepared to discuss a scenario of how the DSAL maneuver is actually accomplished. To begin the scenario, let us assume that the pilot is using the FD to command a desired enroute altitude (collective command), a desired enroute airspeed (cyclic pitch-speed command bar) and a desired heading hold (cyclic roll command bar). At this time the pilot will set the course select knob on the HSI to the known inbound localizer course and will also select the required safe glideslope angle through the AV ARD-3 control head. He may also select a commanded intercept heading to the localizer course through the heading select knob on the HSI. If this heading is different than the one he has previously commanded to hold, the flight direction roll command bar, if he keeps it centered, will command the pilot to the new heading. At no time will he be commanded to exceed a 20° angle of bank in either direction.

As the pilot flies to within the coverage of the landing system, localizer and glideslope flags will retract, and the localizer and glideslope situation will be displayed on the HSI. DME range, range rate and height above touchdown (not radar altitude) will also be displayed on the appropriate raw data indicators (see Figures 9 and 10).

If the pilot is receiving valid DME and localizer data from the landing system, he may now select the localizer (LOC) mode on his FPC (see Figure 8). If the data is valid, the LOC mode will engage and the heading hold will be preempted; the roll command bar on the ADI will now be commanding the proper turns to maintain the correct localizer intercept track course as determined by the DSAL FD computer through guidance data from the landing system (not from the heading hold reference). As the aircraft approaches the localizer course, a turn to capture and track the localizer course will be computed and displayed on the ADI roll command bar; if the pilot keeps the bar centered, he will be keeping the aircraft on localizer all the way to the desired hover or touchdown point in the LZ (the system automatically compensates for anomalies such as crosswinds).

Just as the pilot had selected the LOC mode, as long as valid DME and glideslope data are being received, he will also have selected the approach (APP) and deceleration (DECEL) modes on the FPC (see Figure 8). When these two modes are selected, they will automatically be maintained in an "armed" condition (i.e., APP ARM and DECEL ARM) until capture of the glideslope and transition to the deceleration profile occur.

As the aircraft approaches the glideslope capture point, the FD collective command function will be automatically transferred from the altitude hold (and APP ARM) to the approach (APP) mode; if the pilot keeps his collective command bar centered, he will capture and maintain his selected glideslope all the way to the desired hover point or touchdown in the LZ. Altitude hold is, of course, preempted by the APP mode.

The aircraft approaches the deceleration profile (Figure 1) at the commanded airspeed the pilot has selected. At the DECEL capture point (about 3000 feet DME range for a 60 knot airspeed), the FD cyclic pitch (speed) command function will be automatically transferred from the airspeed hold (and DECEL ARM) mode to the DME range-range rate deceleration mode. If the pilot keeps his cyclic pitch (speed) command bar centered, the aircraft will decelerate to zero ground velocity over the desired hover point in the LZ.

During the DSAL maneuver, as the aircraft passes through 45 knots airspeed, the pedal command bar (the fourth cue on the ADI) comes into view. Up to this time the pilot has been keeping his commanded cyclic turns coordinated by centering his turn coordination ball in the bottom of his ADI. Now, however, he must keep his pedal command bar centered in order to align his aircraft with the inbound approach course (for reasons already explained).

Therefore, simply by keeping all of his DSAL FD command cues centered on the ADI, the pilot, without the burden of calculating his motions, will be providing the proper control inputs to safely and comfortably guide the aircraft to a precise hover point without visual reference to objects outside the cockpit (about a 5 to 10 foot hover).

Prior to commencing the FD DSAL maneuver, the pilot will know a safe go-around or missed approach heading. During the DSAL maneuver, he will dial in this heading with the heading select knob on the HSI (this will have no effect on the FD at this time since the FD is computing turns via localizer course deviation data). If at any point during the DSAL maneuver, down to and including the hover or touchdown in the LZ, the pilot determines that any unsafe condition exists, he can execute the FD go-around (G/A) maneuver. The pilot terminates the DSAL maneuver the instant he pushes the G/A button on his collective control lever and, by centering the FD cues precisely as he has done for the enroute and DSAL maneuvers, he will be providing the control inputs required to climb (about 100 feet per minute)

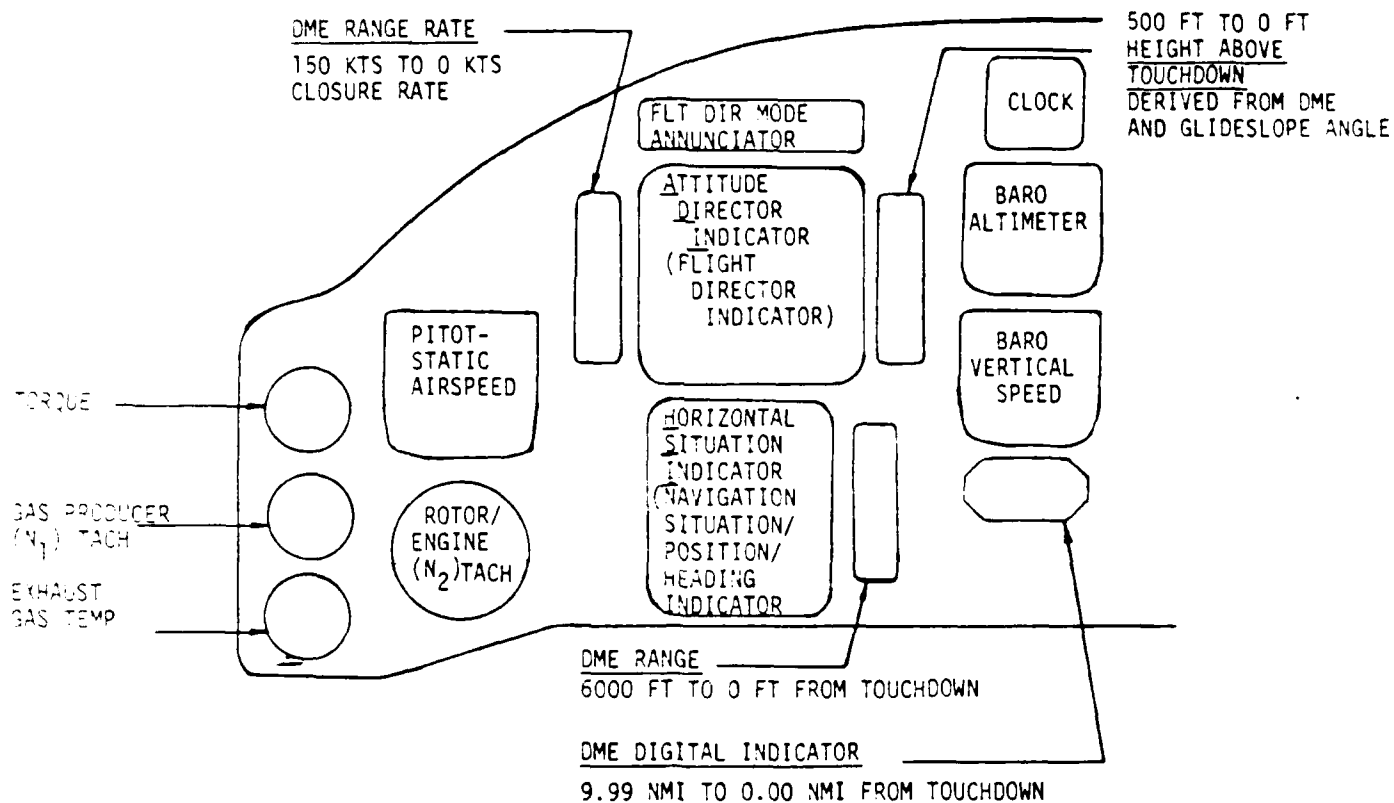


Figure 9 Legend for flight director instrument panel layout, DSAL project aircraft (Army 18261).

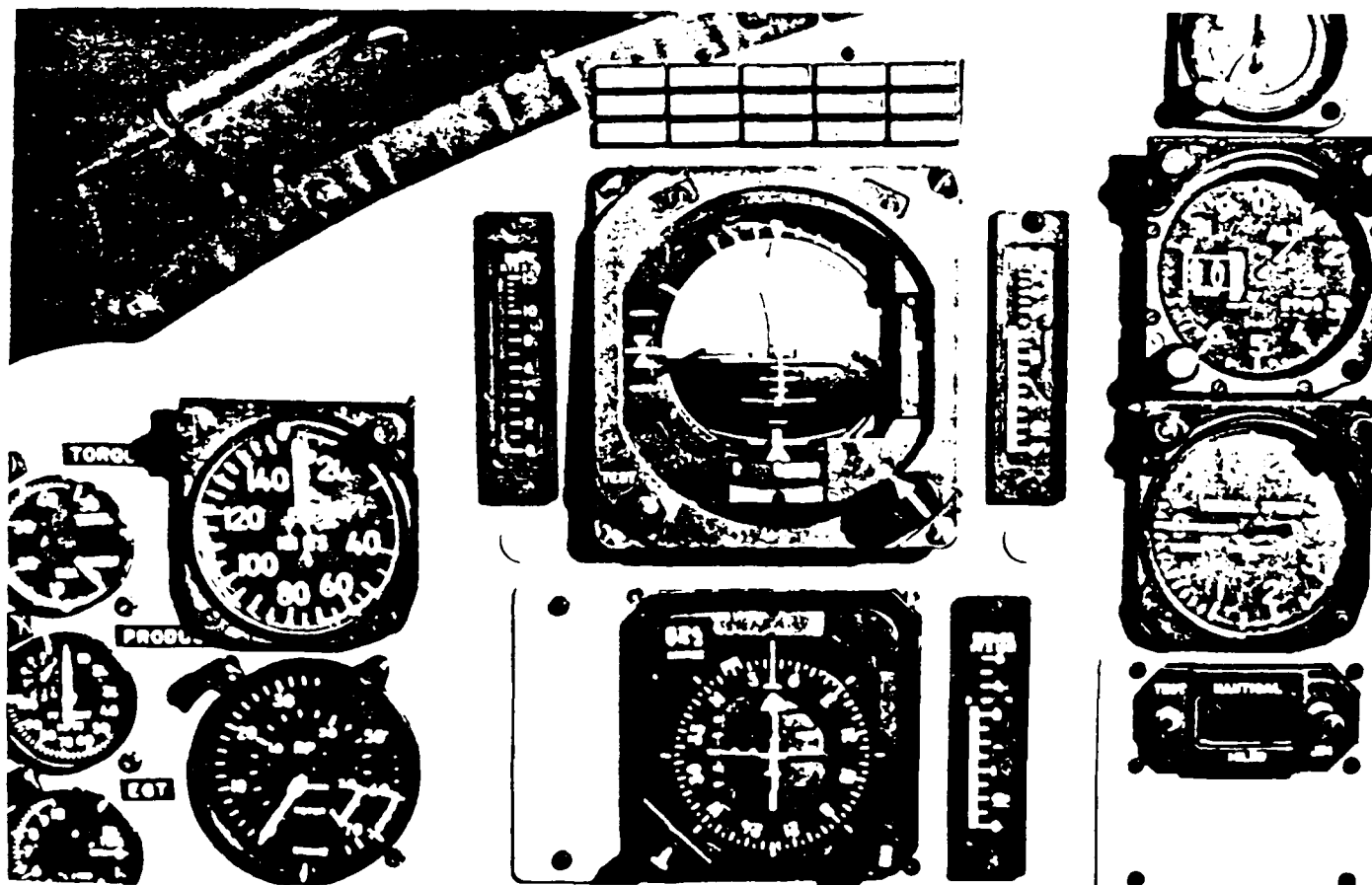


Figure 10. Flight director instrument panel, DSAL project aircraft (Army 18261).

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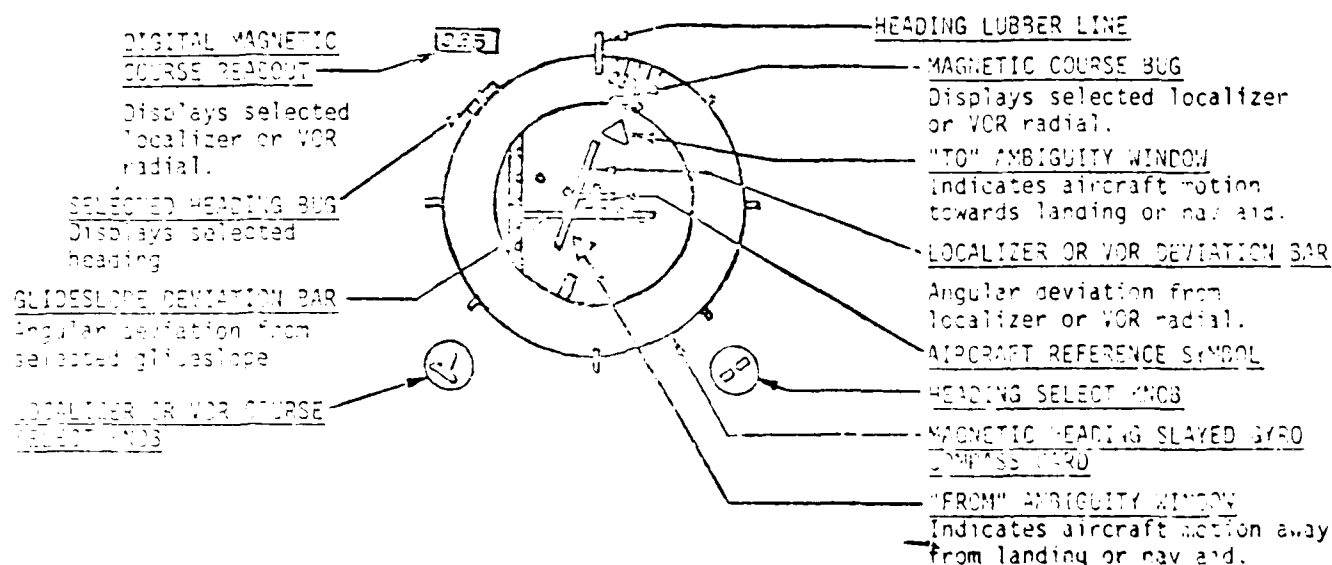


Figure 11. Legend for Horizontal Situation Indicator (HSI) functions (navigation situation/position/heading indicator).

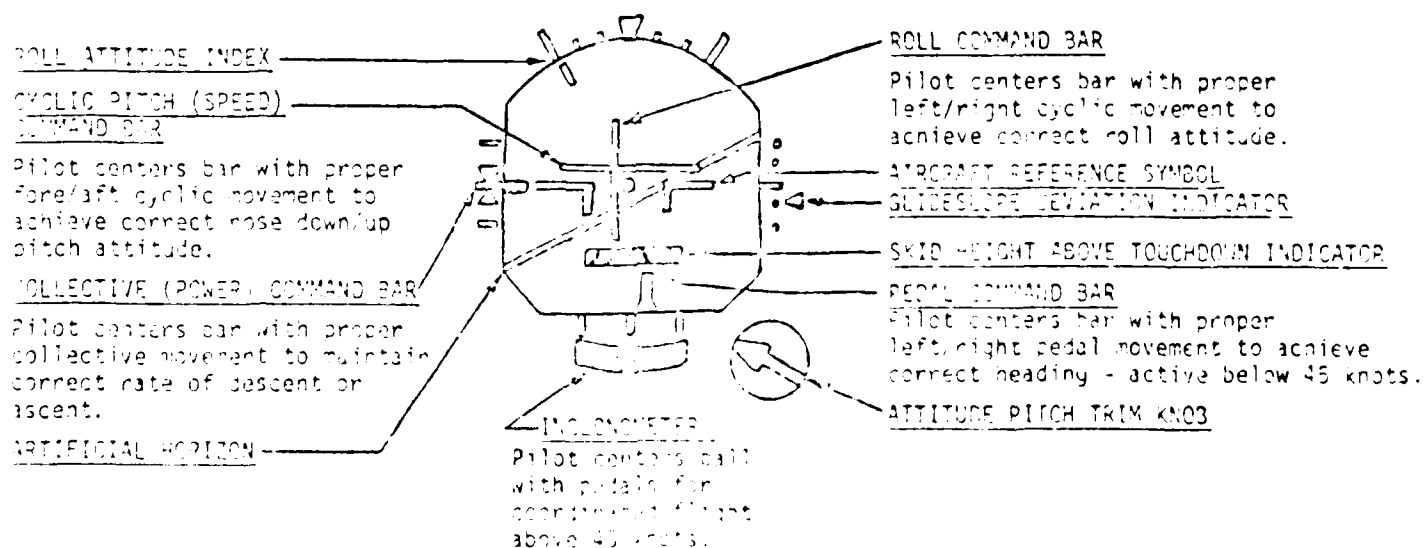


Figure 12. Legend for Attitude Director Indicator (ADI) functions (cyclic, collective, pedal control command/attitude indicator).

accelerate to a safe airspeed (about 70 knots) and turn to and maintain the preselected G/A heading.

Summary and Conclusions

The previous scenario (enroute navigation, IMC DSAL and go-around) for a helicopter IMC operation is not a hypothetical scenario - it has been routinely and reliably accomplished hundreds of times under simulated IMC to zero-zero conditions. It has even been accomplished with hands (and feet) off of the controls by coupling the FD command data (the data that goes to the ADI) to the 4-axis autopilot on board the DSAL project aircraft and allowing it to fly the DSAL maneuver by itself.

The Appendix to this paper contains sample data from 3 FD (labeled "MANUAL APPROACH") and from 3 Autopilot (labeled "AUTOMATIC APPROACH") approaches. This data is an illustration of the performance that has been achieved with the 4-cue/4-axis DSAL flight director autopilot (FD/AP) system, with guidance from a scanning beam landing system. This data shows that the IMC DSAL maneuver can be flown from practically any intercept altitude (1000 feet and 200 feet shown), along any glideslope (6 and 12 degrees shown) by either the pilot, through the FD, or by the autopilot, to a stable hover over the desired landing point. The data shows further, that when that hover point has been reached, it is within 1 to 5 feet of the desired glideslope and localizer centerlines. Most importantly, this data illustrates that true IMC helicopter approach and landing capability is here, today, for those who wish to use it.

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Acknowledgements

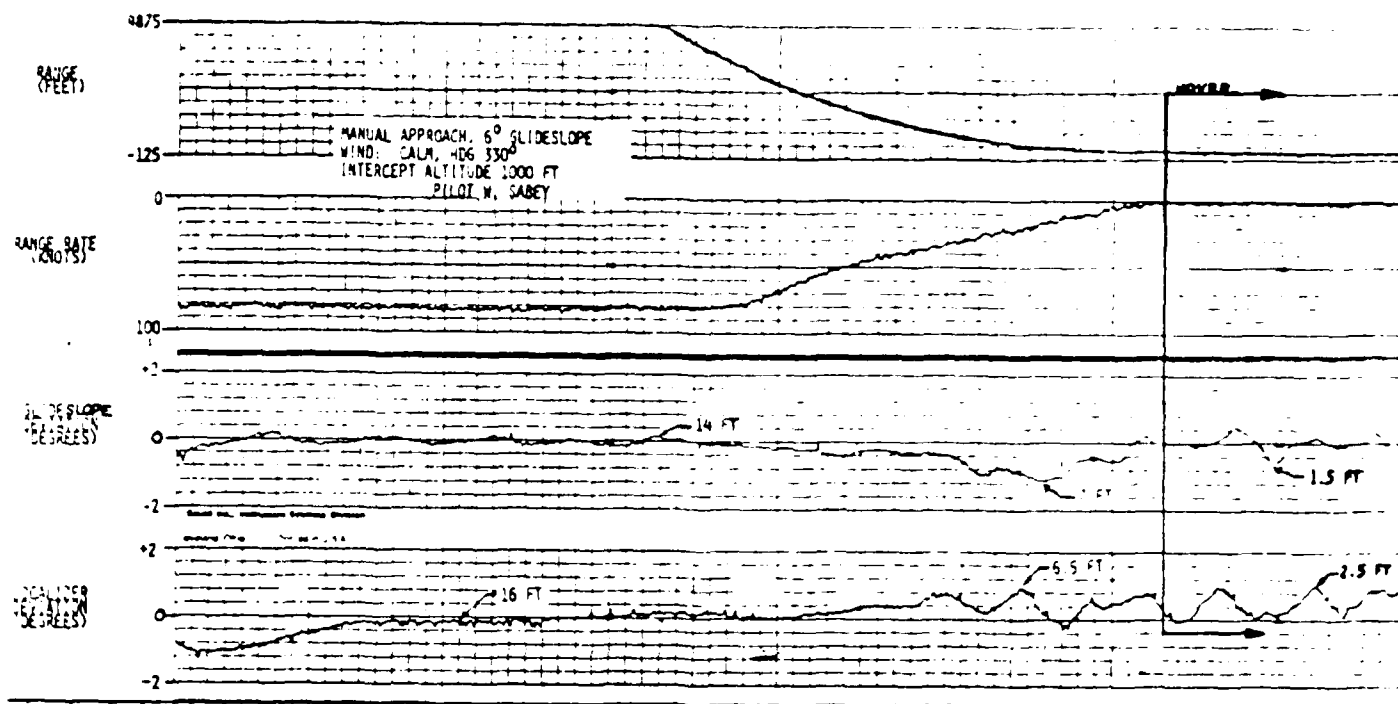
The authors wish to express their appreciation to all of the persons who have contributed to the research which has provided the basis for this paper. In particular, the authors wish to acknowledge the contributions of Messrs. Walter Sabey and Thomas McNamara of the ERADCOM Flight Test Activity, Lakehurst, NJ, who, as project pilots for our decelerated steep approach and landing system flight test programs, provided invaluable aviator and technical expertise which led to the realization of a truly flyable helicopter IFR decelerating steep approach and landing system.

Special acknowledgement and appreciation is also extended to Mr. Robert P. Boriss, formerly with our Landing Branch, and Mr. Rod Iverson of Sperry Flight Systems, whose work in the development of the theory and hardware for the helicopter IFR decelerating steep approach and landing system, provided the nucleus for ultimately extending the unique operational capabilities of the helicopter to the IFR domain.

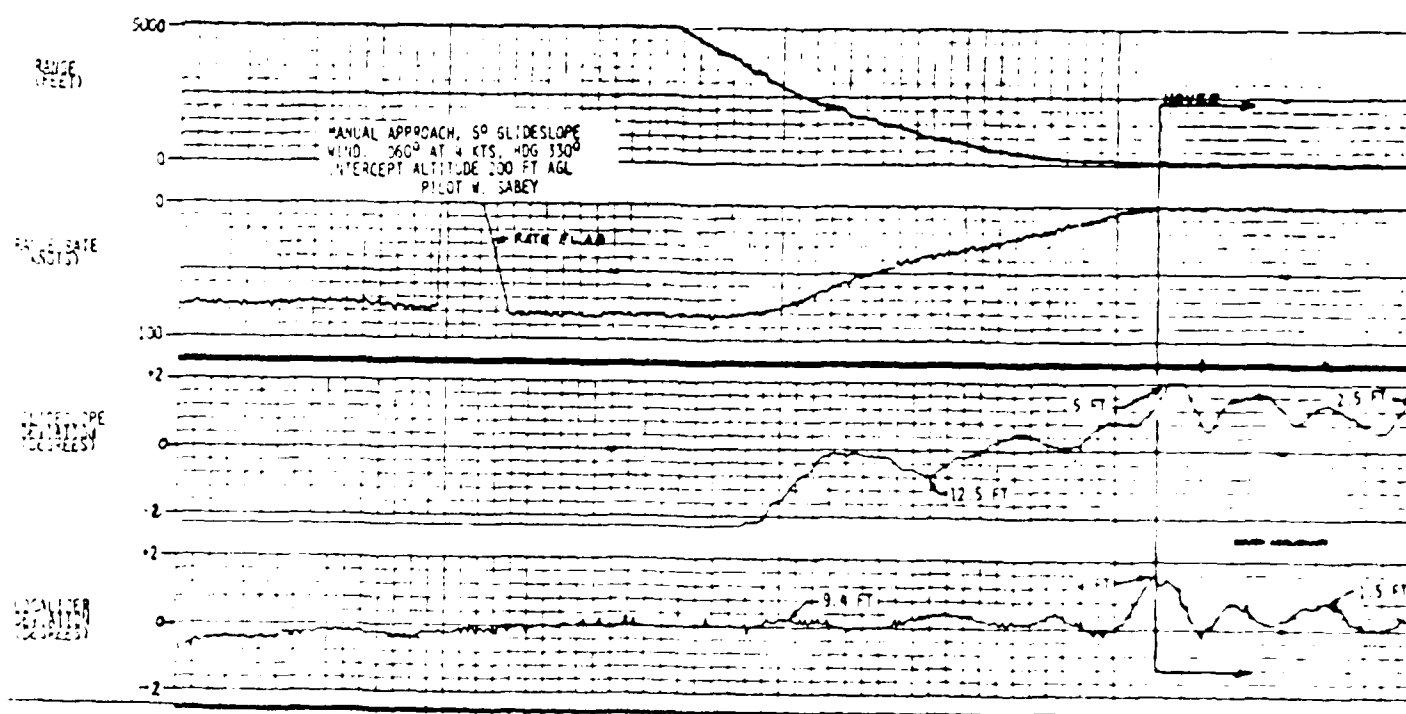
APPENDIX

This appendix contains sample data from 6 DSAL maneuvers. This analog data was recorded on a multi-channel strip chart recorder which was part of the DSAL project aircraft's airborne data recording system. The data plots are "real-time" plots of glideslope and localizer angular tracking error in degrees, along with range and range rate

performance. Localizer and glideslope deviations in "feet" from centerline are superimposed on the angular data in spots representing the maximum displacements from course centerline. Note, that all approaches converge to a relatively stable hover over the spot of intended landing.



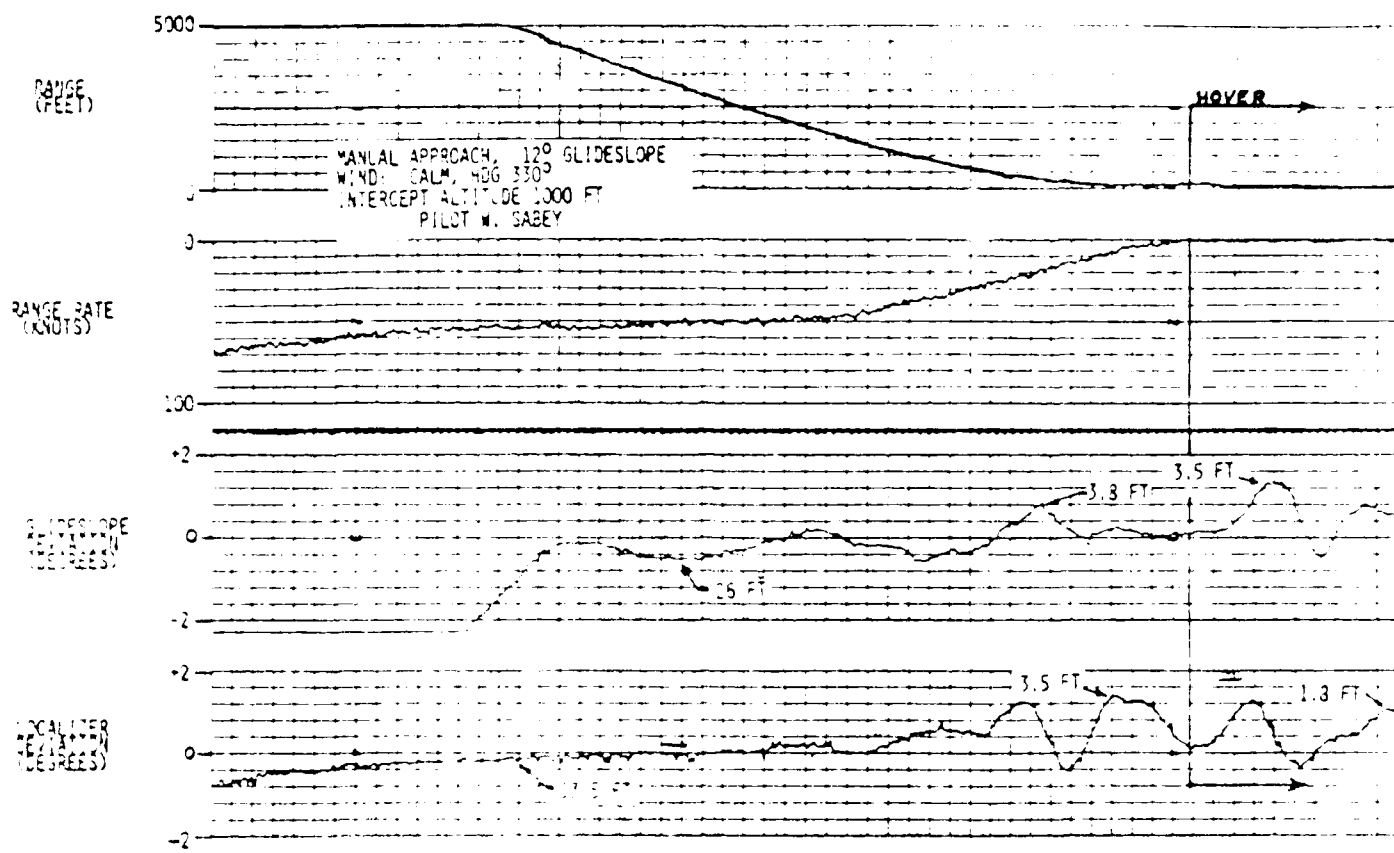
Appendix, Figure 1. Flight director DSAL along a 6 degree glideslope; initiated from a 1000 ft glideslope intercept altitude.



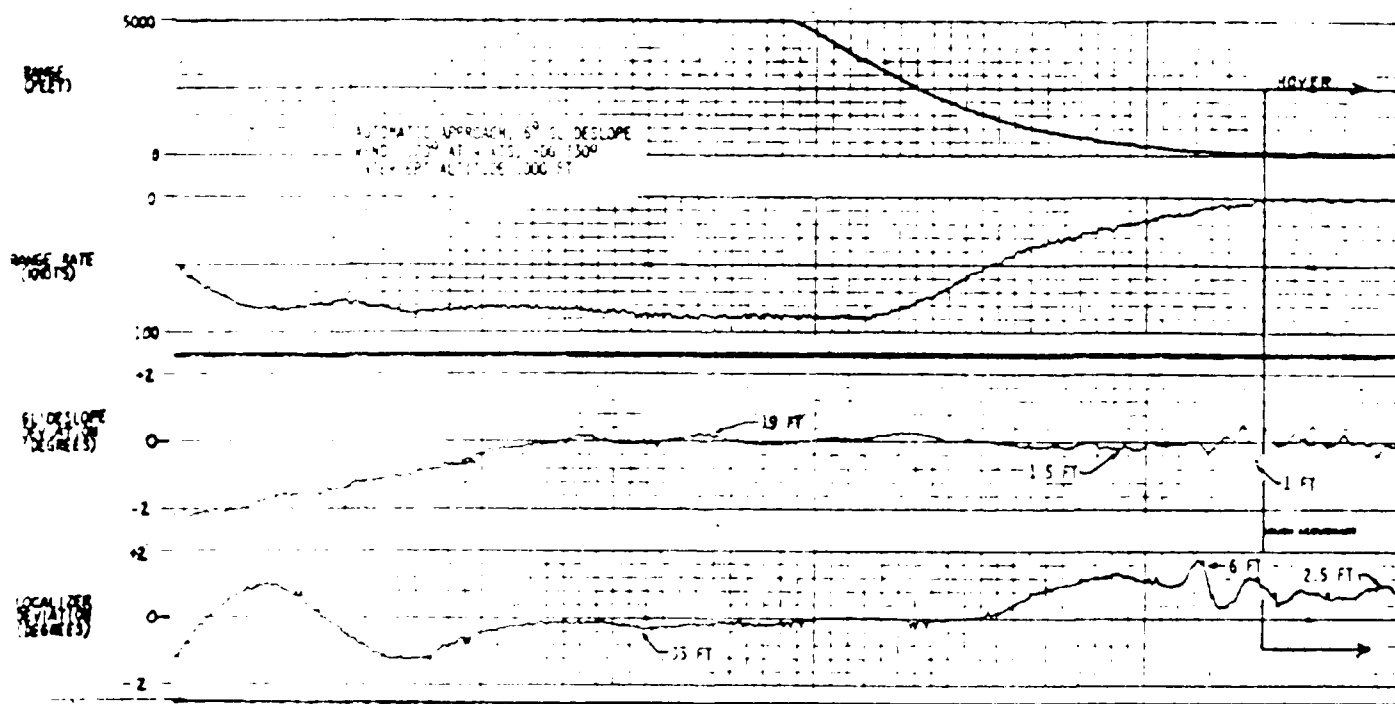
Appendix, Figure 2. Flight director DSAL along a 6 degree glideslope, initiated from a 200 ft glideslope intercept altitude.

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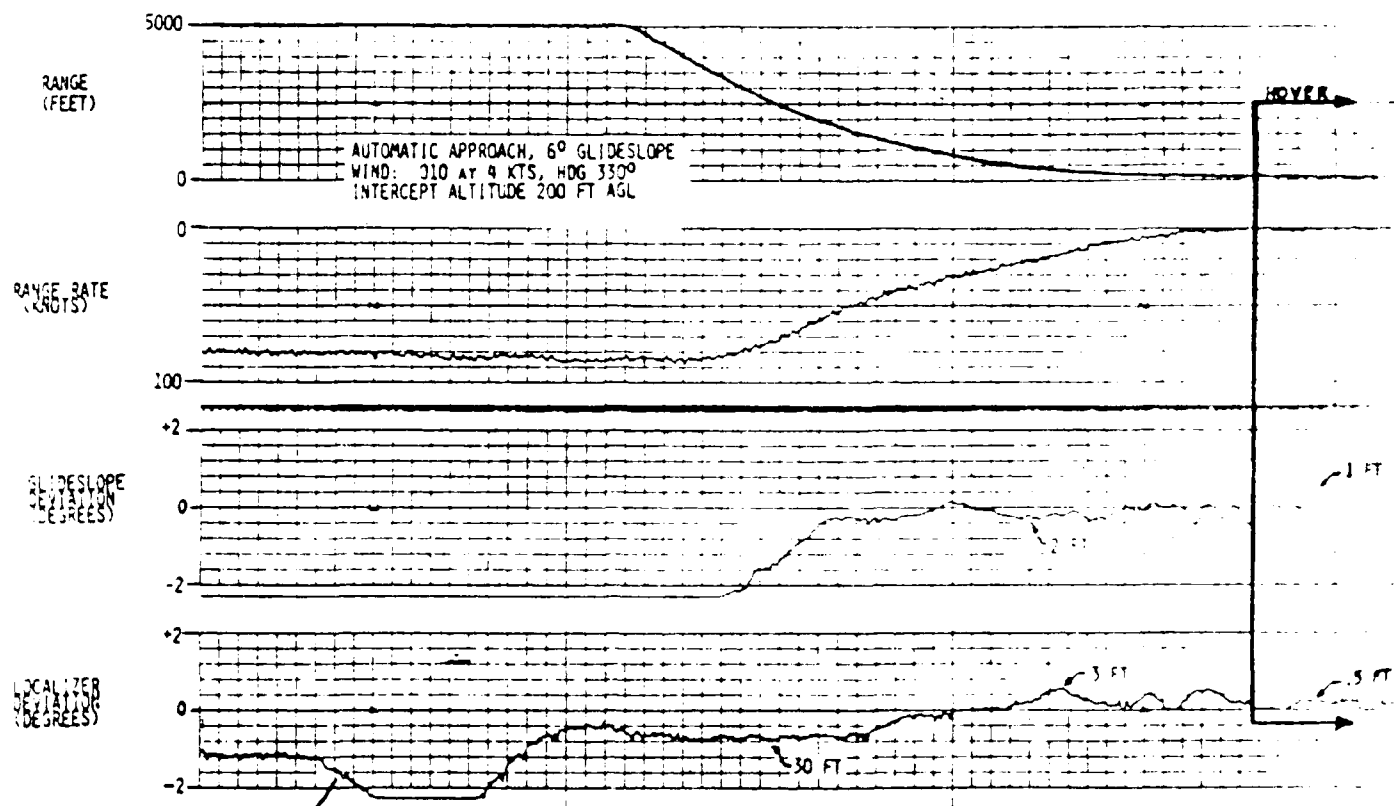
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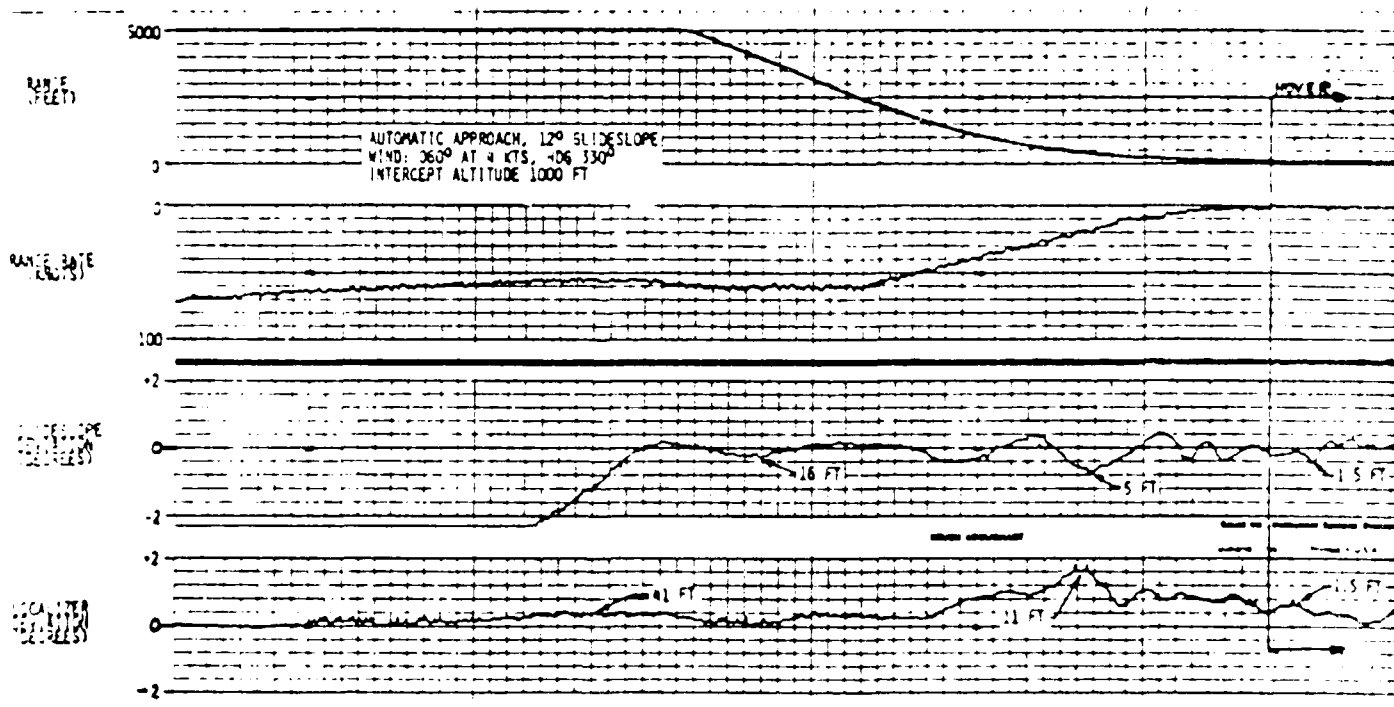
Appendix, Figure 3. Flight stream in CAL along a 12 degree glideslope, initiated from a 1000 ft glideslope intercept altitude.



Appendix 4, Figure 4. Autopilot CAL along a 6 degree glideslope; initiated from a 1000 ft glideslope intercept altitude.



Appendix, Figure 5. Autopilot DSAL along a 6 degree glideslope; initiated from a 200 ft glideslope intercept altitude.

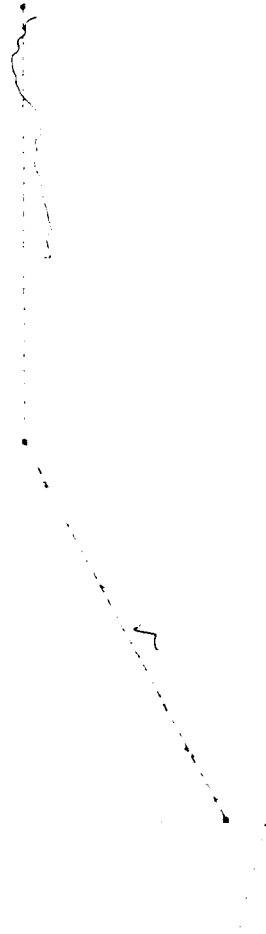
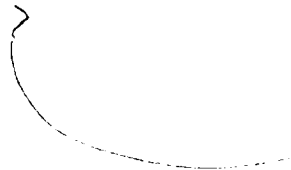
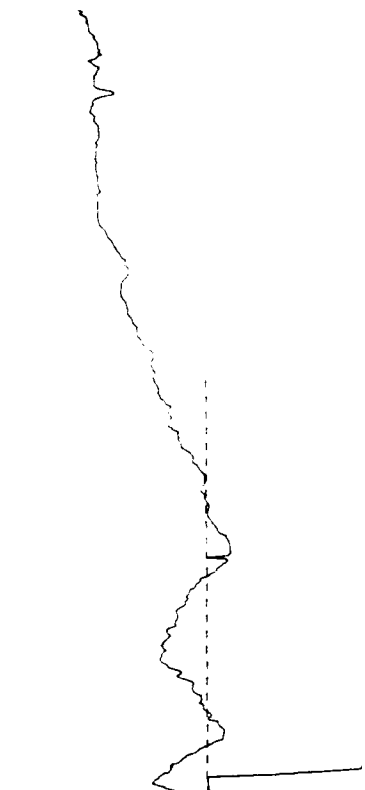


Appendix, Figure 6. Autopilot DSAL along a 12 degree glideslope; initiated from a 1000 ft glideslope intercept altitude.

APPENDIX E
PLOTS OF AIRCRAFT POSITION

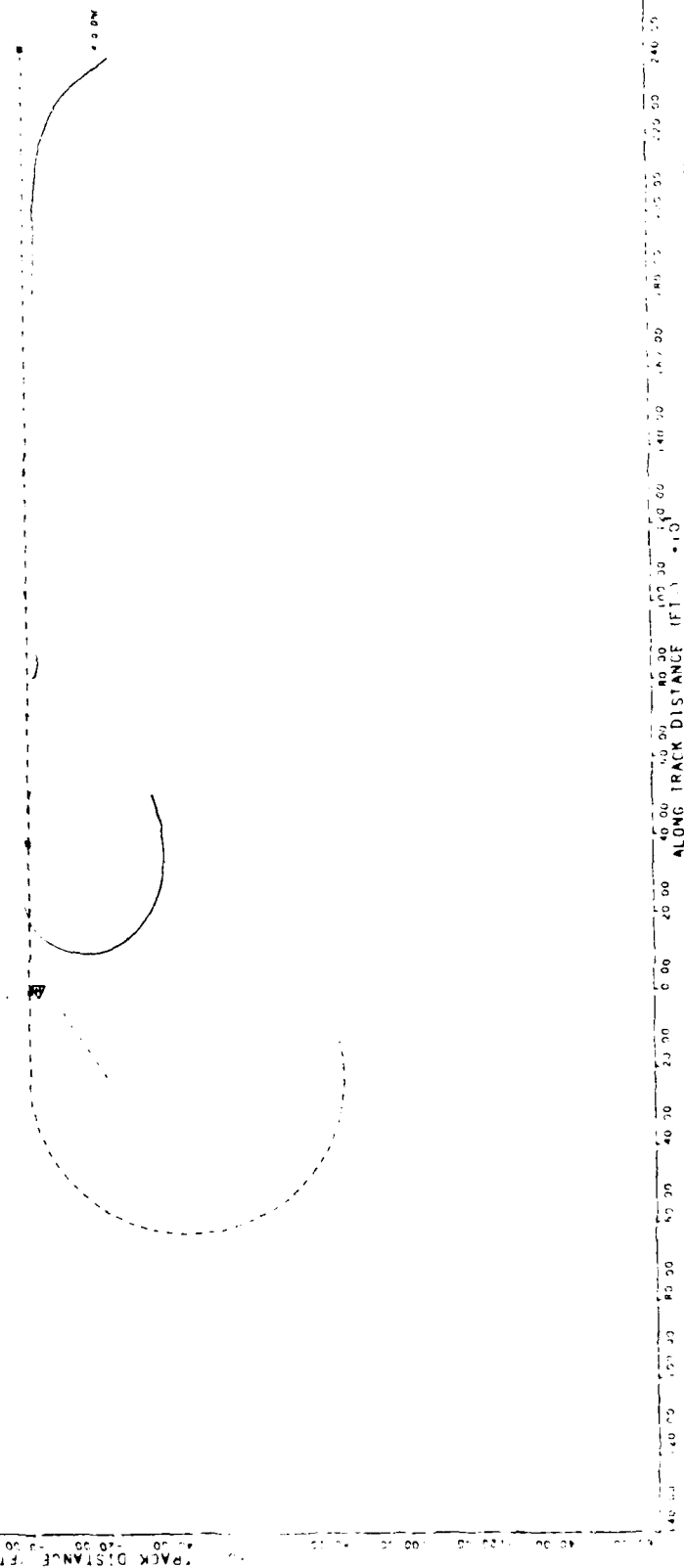
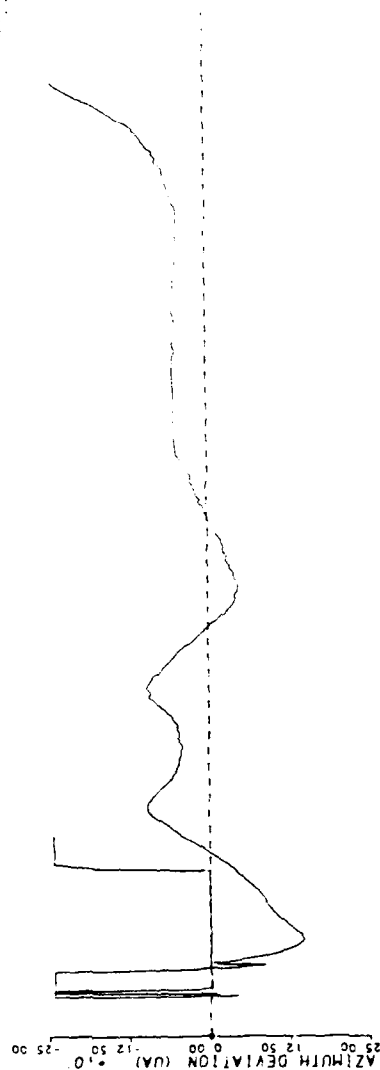
0.000 4.512 85.115 5 APP 5 RUN 35
 START TIME = 10.15.9
 END TIME = 10.24.11
 ALTITUDE = 3.00
 ALTITUDE = 3.00
 WIND DIRECTION = 290
 WIND SPEED = 11

ELEVATION DEVIATION (UVA) * 10
 25.00 0.00 12.50 25.00



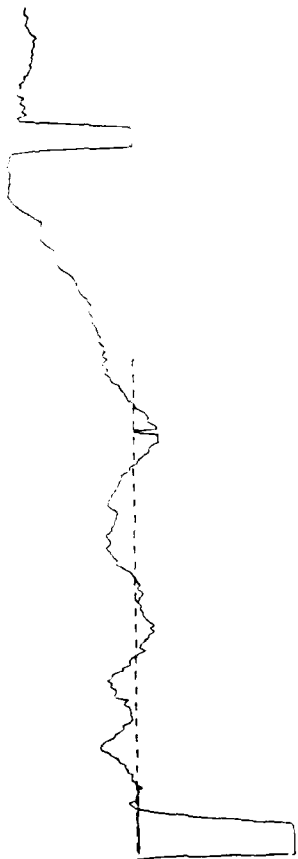
ALONG TRACK DISTANCE (FT) * 10
 0.00 20.00 40.00 60.00 80.00 100.00

4-SEP 85 MES APP'S RMT 35
 CLOSURE TIME = 0029
 CLOSURE ALT = 1000
 BARO SET = 30.0
 AZIMUTH = 350
 ELEVATION = 300
 WIND DIRECTION = 290
 WIND SPEED = 11

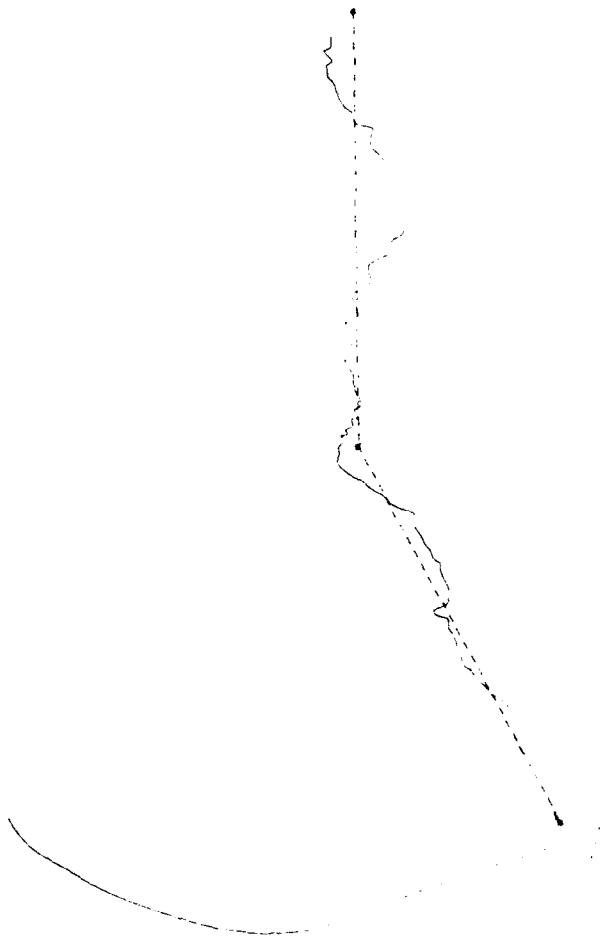


4 SEP 85 MES APP 5 MAY 35
 111.3 20
 111.8 16
 30.01
 3.50
 3.00
 WIND DIRECTION = 280
 WIND SPEED = 12

ELEVATION DEVIATION (UA) *10
 25.00
 12.50
 0.00
 -12.50
 -25.00



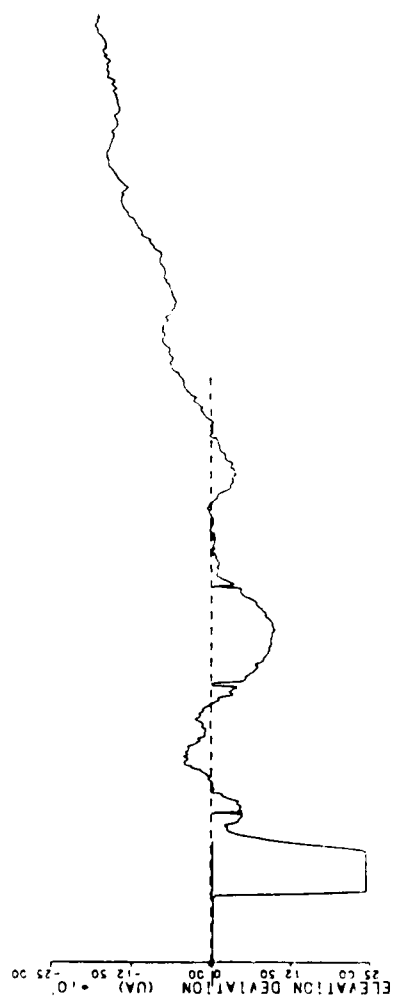
111.3 20
 111.8 16
 30.01
 3.50
 3.00



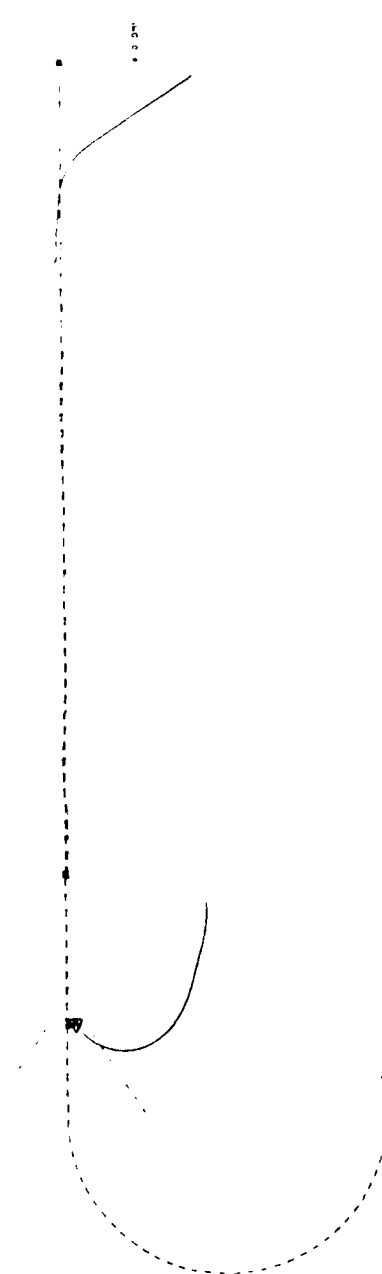
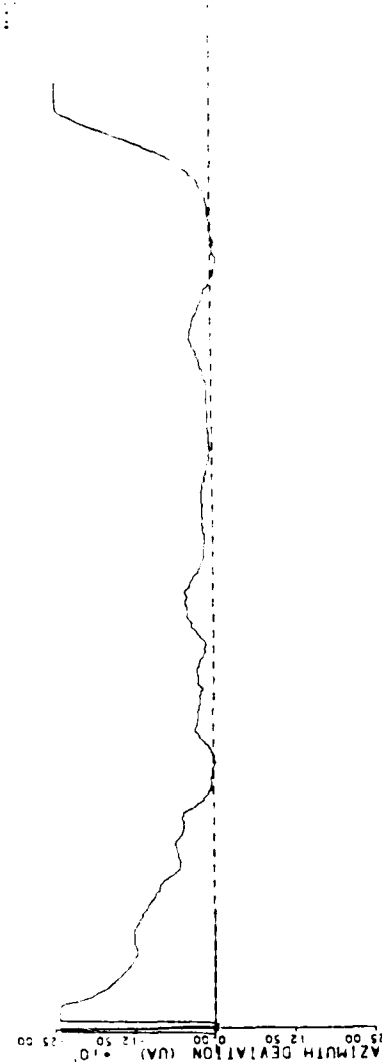
ALUN TRACK DISTANCE (FT) *10
 25.00
 12.50
 0.00
 -12.50
 -25.00



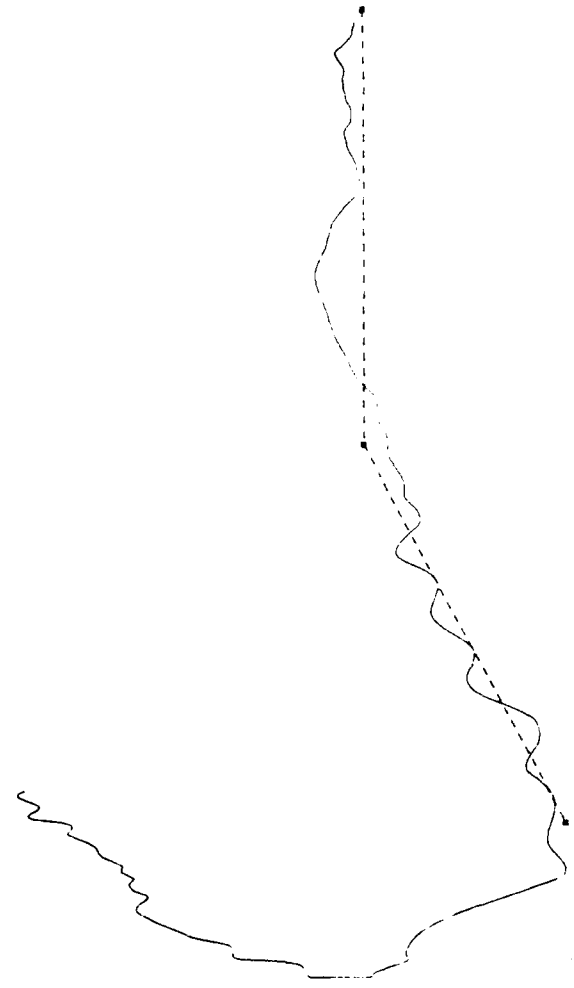
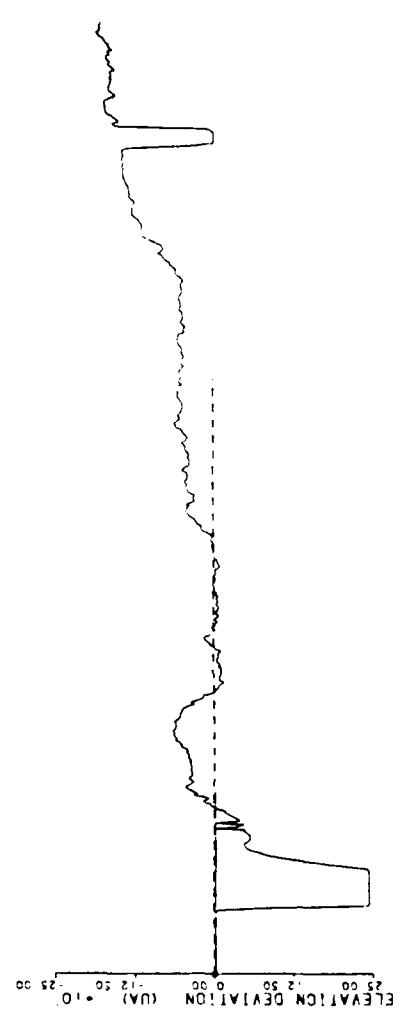
RUN 17
 START TIME - 13 SEP 85 15:00
 STOP TIME - 13 SEP 85 15:40
 BARO SET - 29.91
 AZIMUTH - 3.50
 ELEVATION - 3.00
 WIND DIRECTION - 270
 WIND SPEED - 13



RUN 1
 START TIME - 13 SEP 85 15:35
 STOP TIME - 13 SEP 85 16:10
 ELEVATION - 3.00
 WIND DIRECTION - 270
 WIND SPEED - 13



RUN # 1
 START TIME = 14 14 20
 END TIME = 14 22 20
 RBD SET = 3 00
 ELEVATION = 0 00
 WIND DIRECTION = 270
 WIND SPEED = 10



ALONG TRACK DISTANCE (FT)

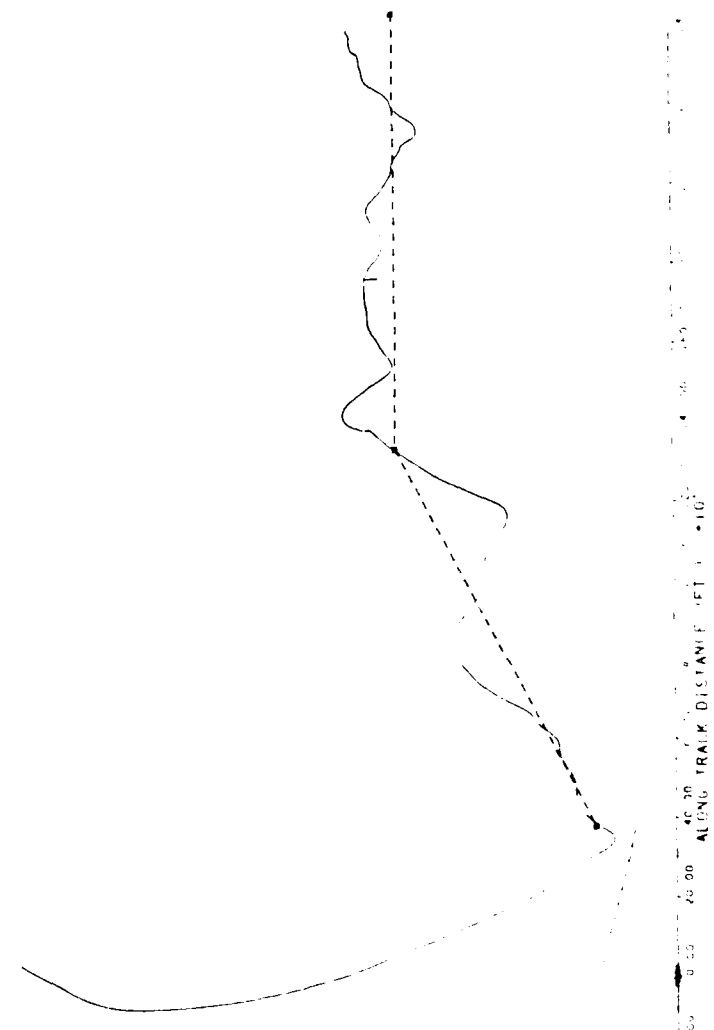
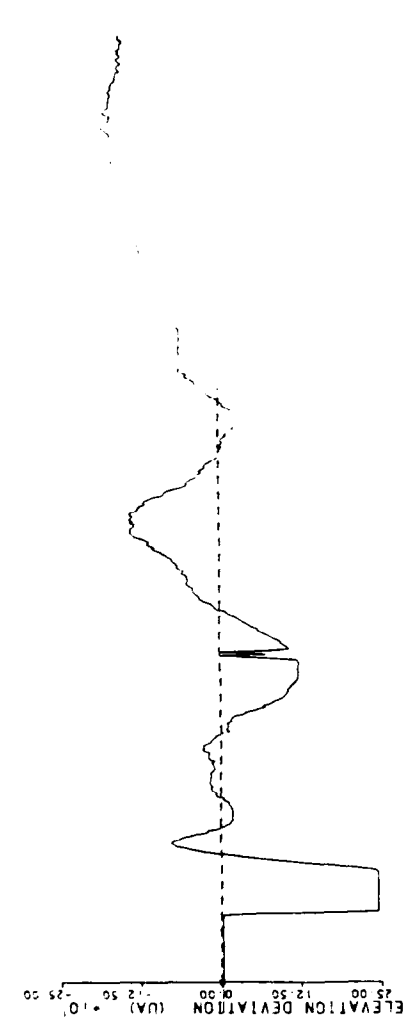
RUN 0 -
 STAMP 4 SEP 85 MLS APP 5 RUN 35
 START TIME - 14 19 20
 STOP TIME - 14 22 40
 WIND DIR - 300
 ELEVATION - 0.03
 WIND DIRECTION - 270
 WIND SPEED - 10

CROSS TRACK DISTANCE (FT) *10
 140 00 120 00 100 00 80 00 60 00 40 00 20 00 0 00 -20 00 -40 00 -60 00 -80 00 -100 00 -120 00 -140 00

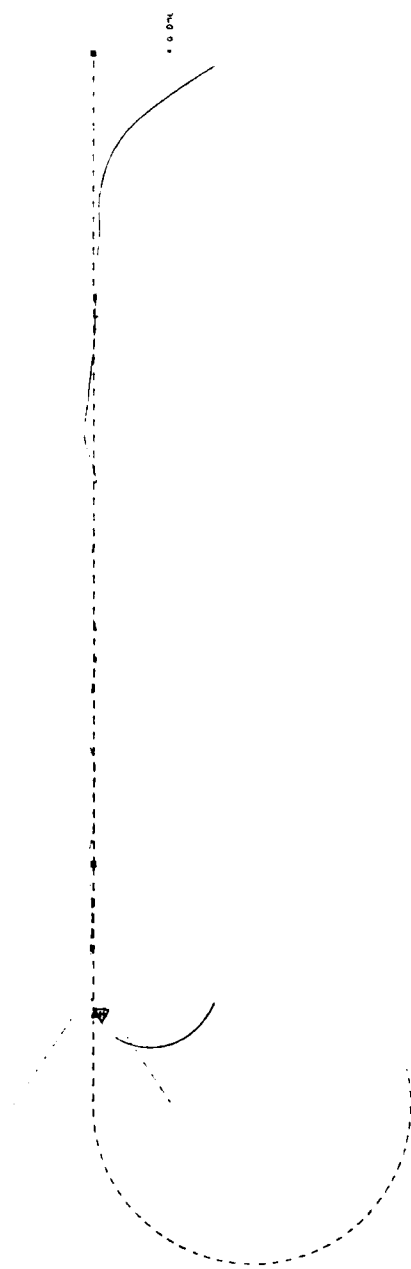
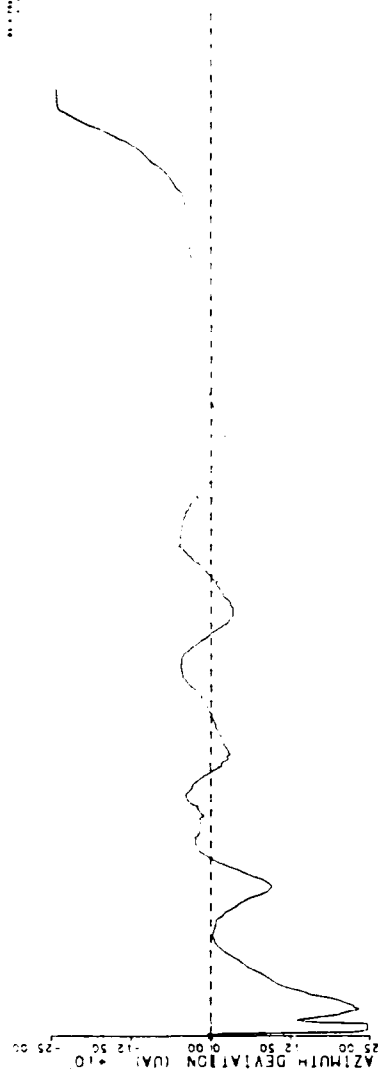
AZIMUTH DEVIATION (UA) *10
 25 00 20 00 15 00 10 00 5 00 0 00 -5 00 -10 00 -15 00 -20 00 -25 00

ALONG TRACK DISTANCE (FT) *10
 140 00 120 00 100 00 80 00 60 00 40 00 20 00 0 00 -20 00 -40 00 -60 00 -80 00 -100 00 -120 00 -140 00

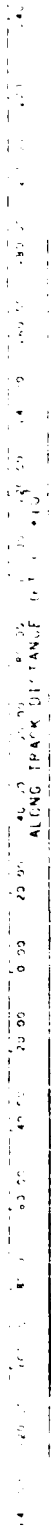
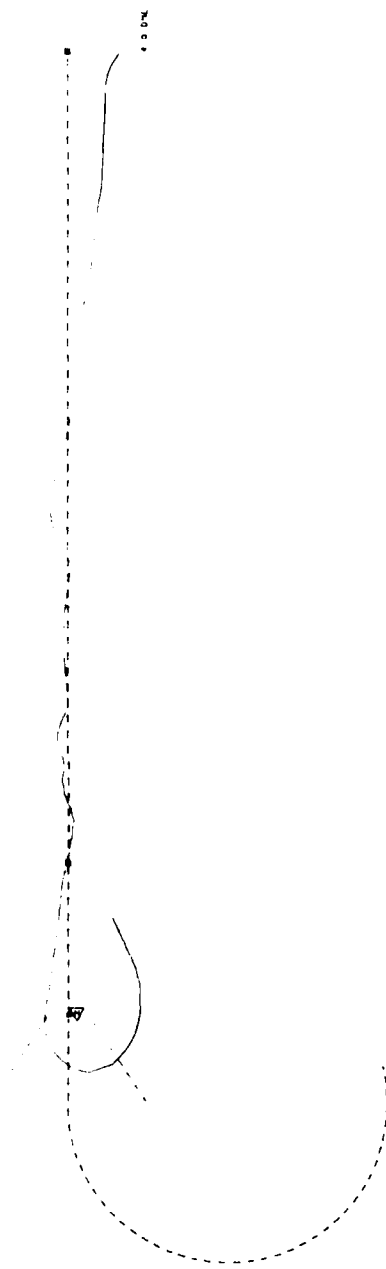
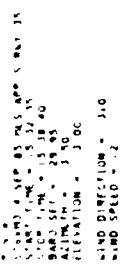
RUN 9 -
 START 4 SEP 85 15:55 APP 5 RUN 35
 START TIME = 14:51:44
 STOP TIME = 14:57:39
 RUNS LEFT = 158
 AZIMUTH = 340
 ELEVATION = 3.00
 WIND DIRECTION = 310
 WIND SPEED = 12



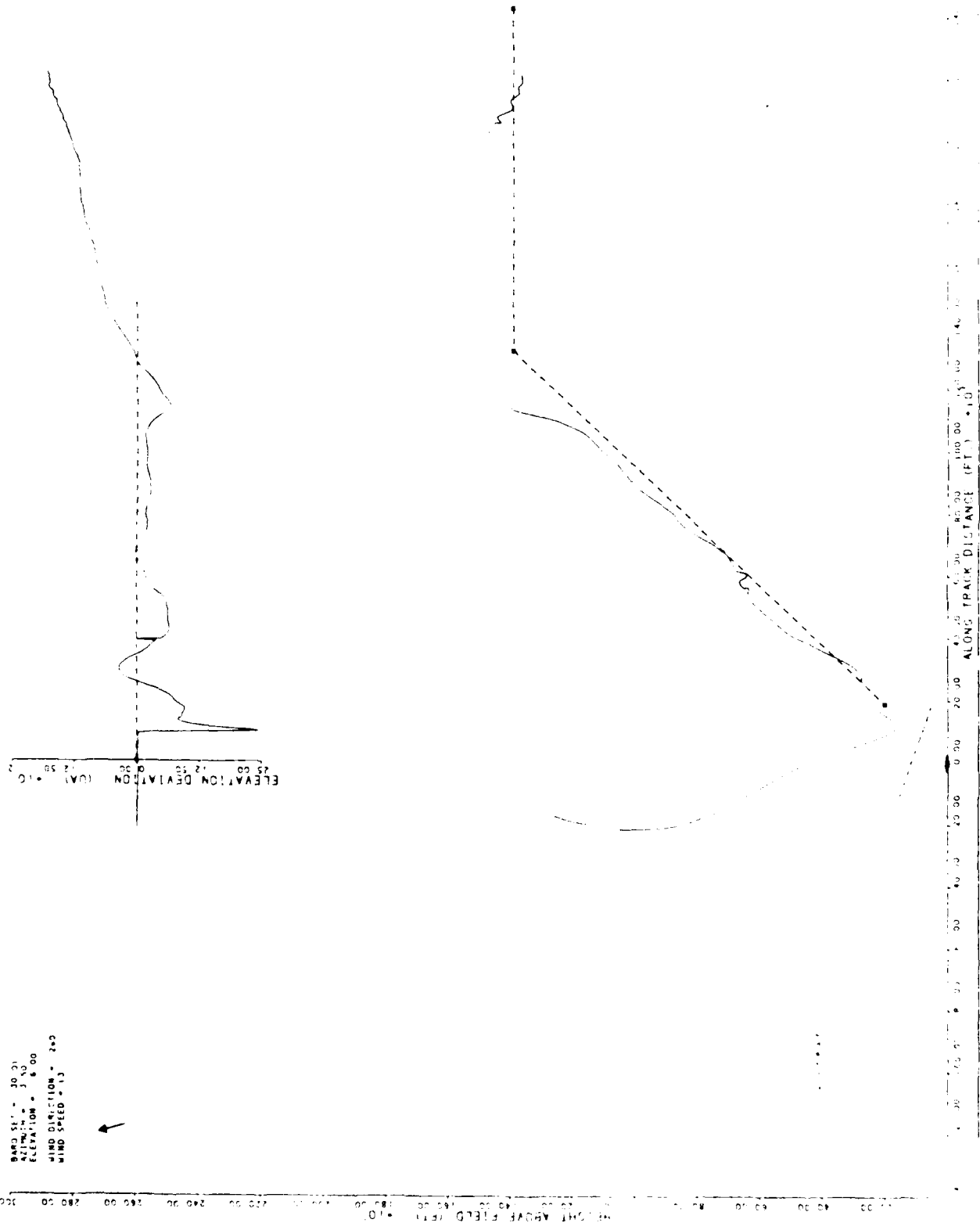
RUN # 1
 START TIME = 14 51 44
 STOP TIME = 14 57 35
 BARO SET = 29.96
 ALTITUDE = 1000
 ELEVATION = 3000
 WIND DIRECTION = 310
 WIND SPEED = 12



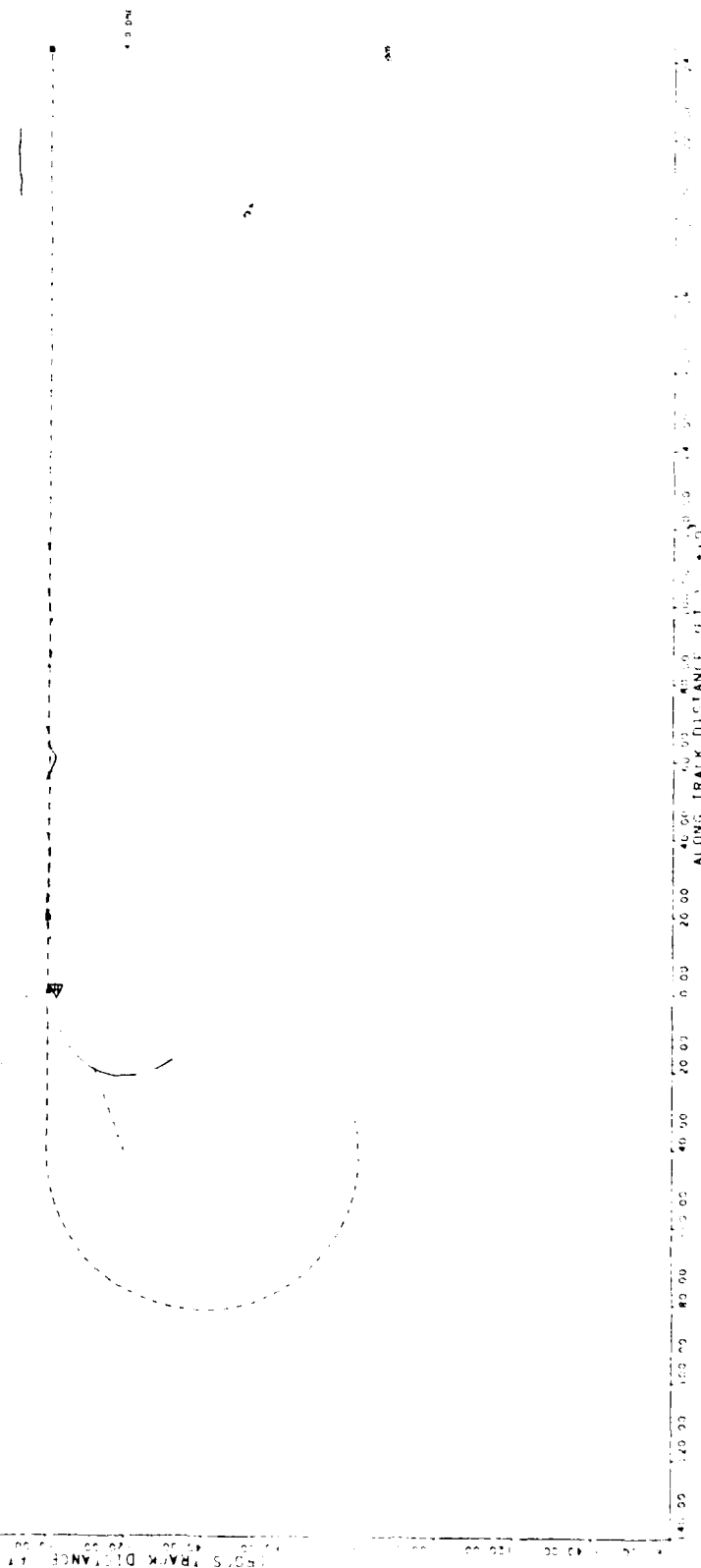
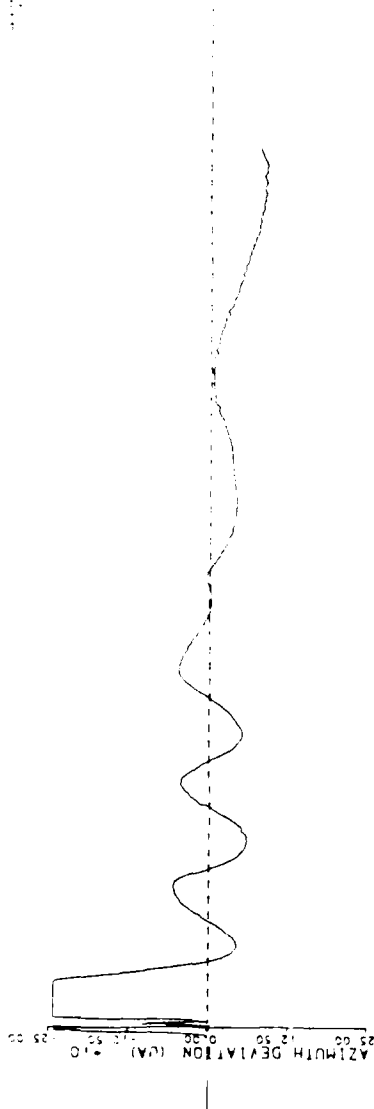
66-90 8 30
LUN, TRAM, DISTANCE 11



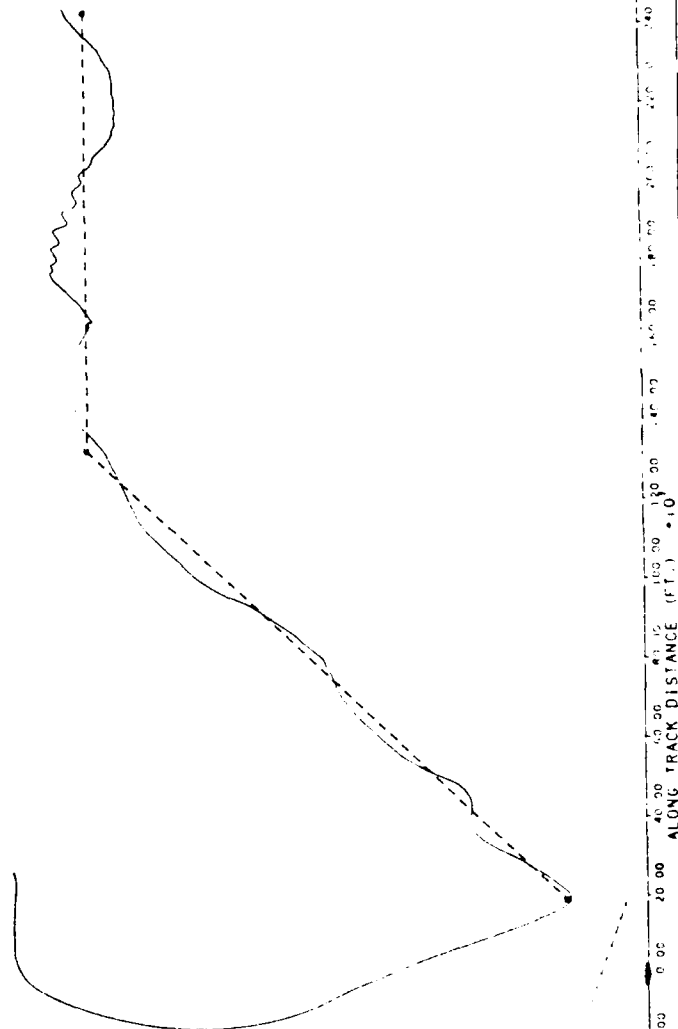
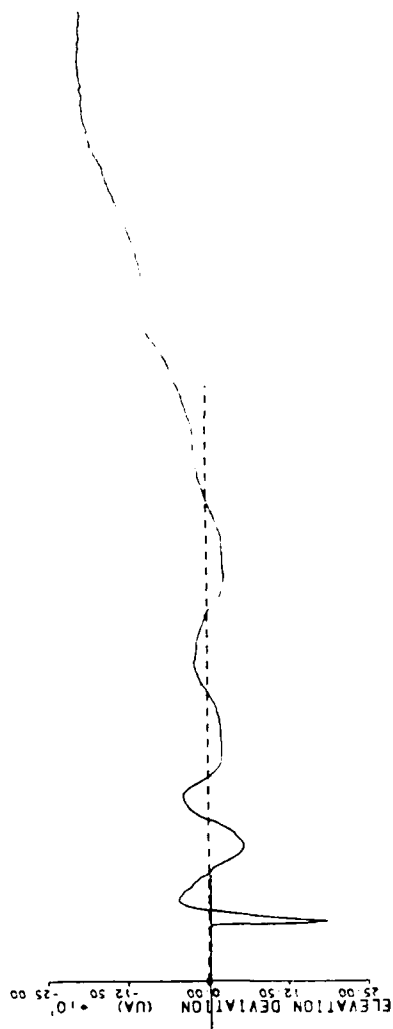
BARO 51.1 - 30.0
 WIND ST - 30.0
 ELEVATION - 6.00
 WIND DIRECTION - 240
 WIND SPEED - 15



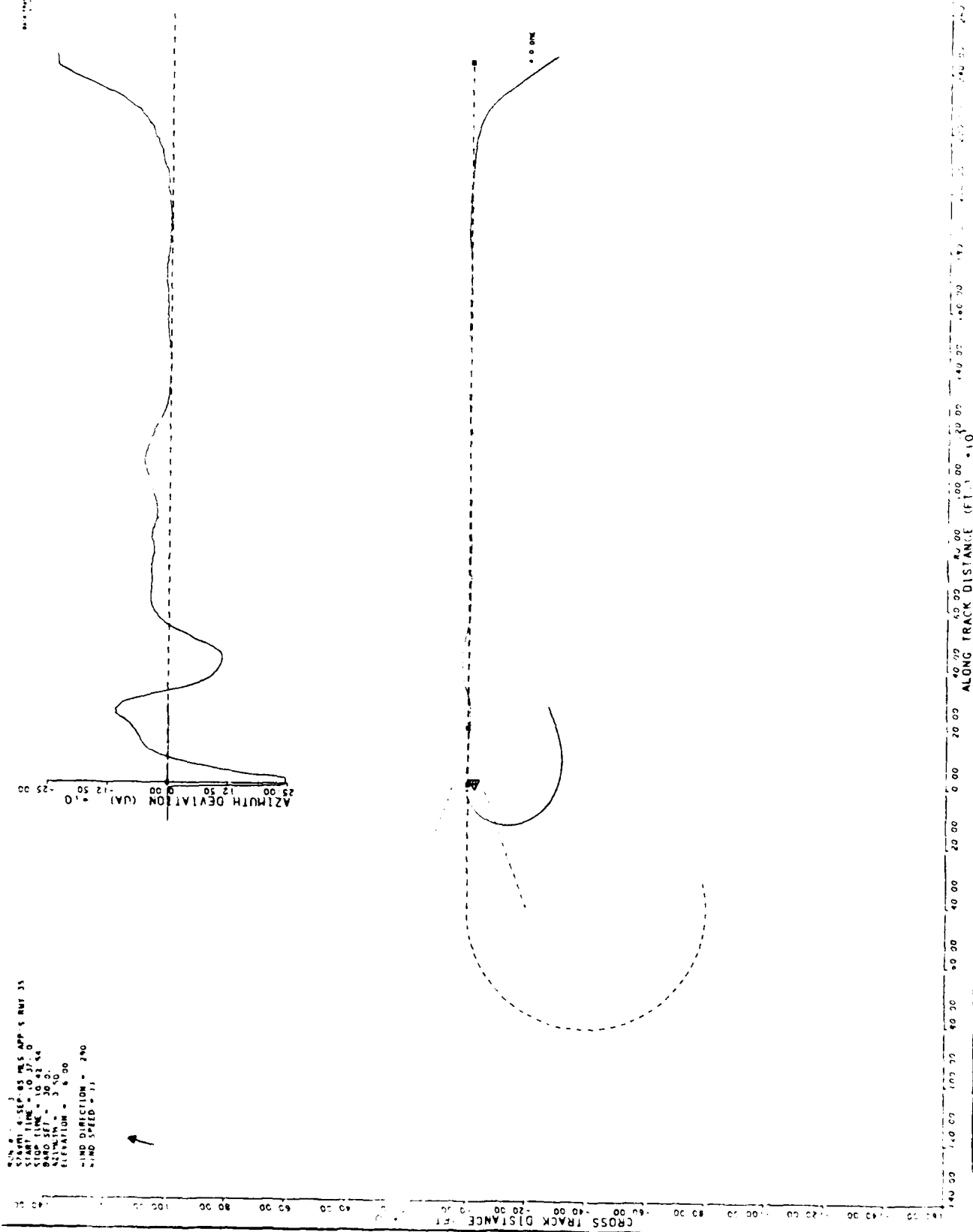
1. 4. 5. 6. 7. 8. 9. 10. 11. 12. 13. 14. 15.
 START TIME - 10.10.14
 STOP TIME - 10.15.12
 BAND 127 - 30.01
 ELEVATION - 9.00
 WIND DIRECTION - 280
 WIND SPEED - 13



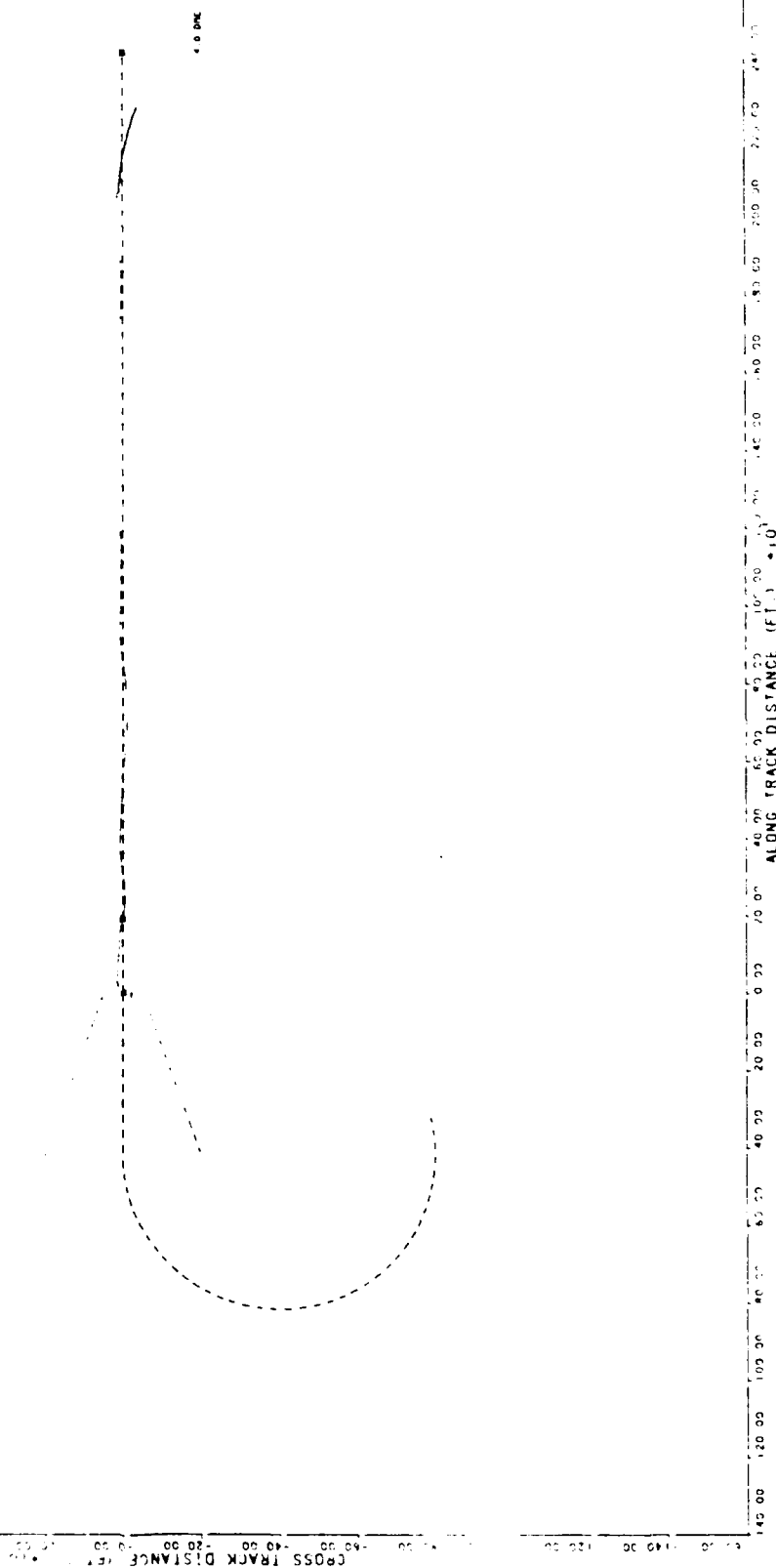
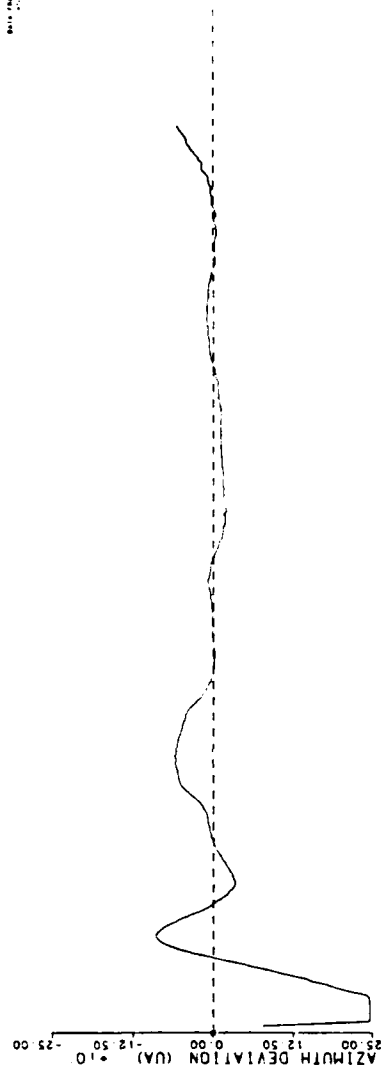
RUN # 2
 START TIME - 10 42 54
 STOP TIME - 10 42 54
 BARO SET - 30.5
 AZIMUTH - 350
 ELEVATION - 6.00
 WIND DIRECTION - 280
 WIND SPEED - 11



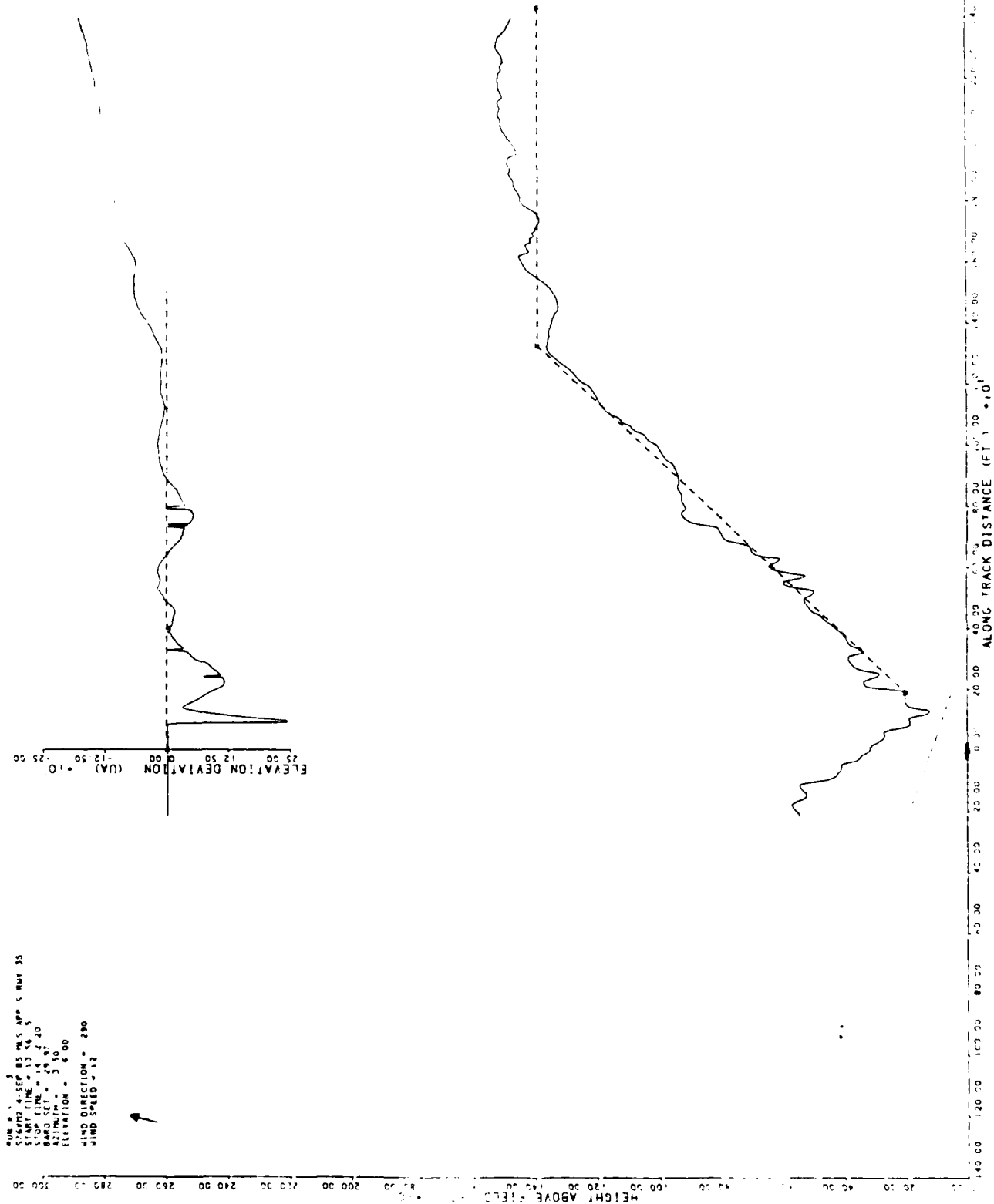
1. 4 SEP 85 MLC APP 5 MAY 85
 START TIME = 10 37 0
 STOP TIME = 10 42 54
 BAND SET = 30 0
 ELEVATION = 5 00
 WIND DIRECTION = 290
 WIND SPEED = 15



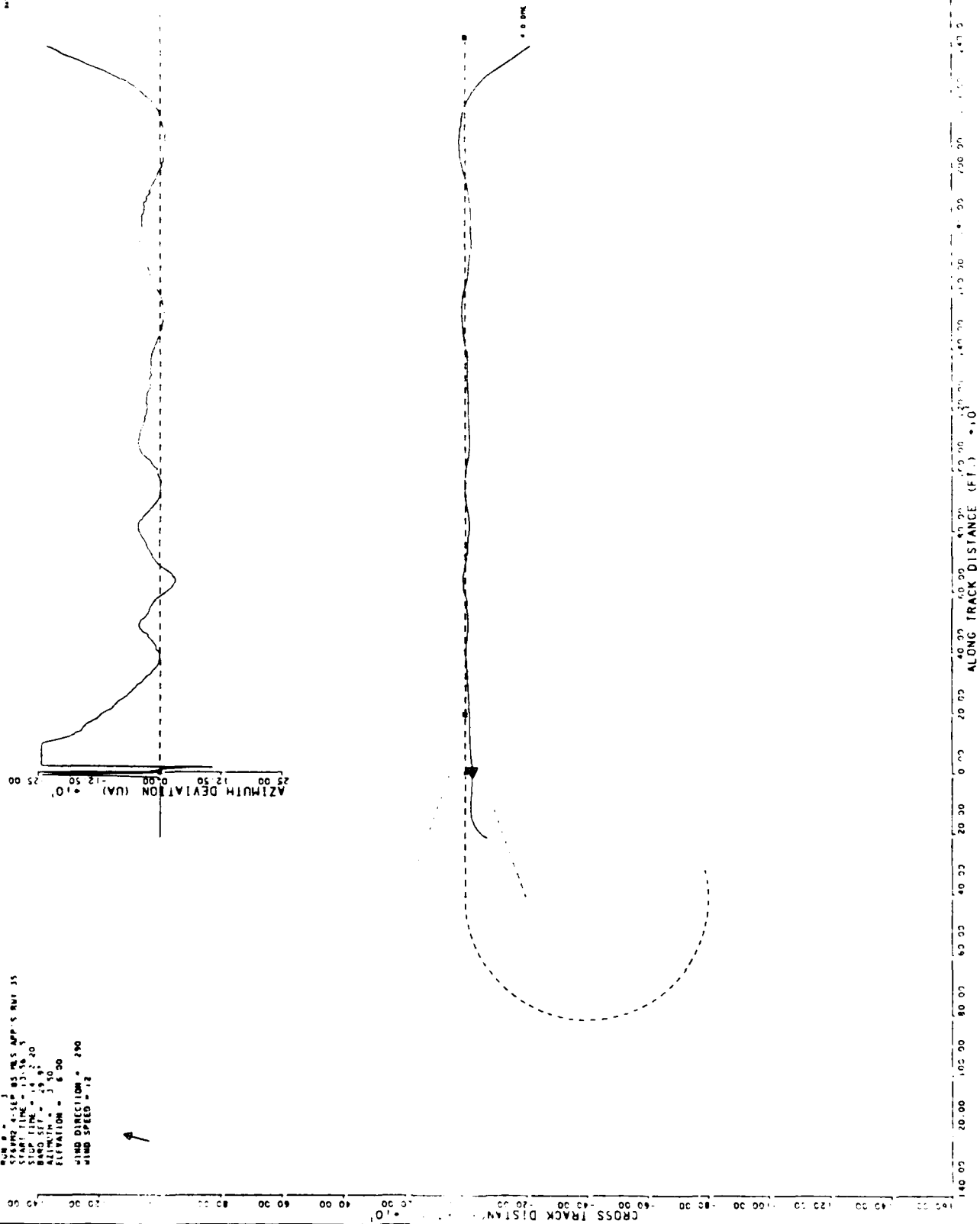
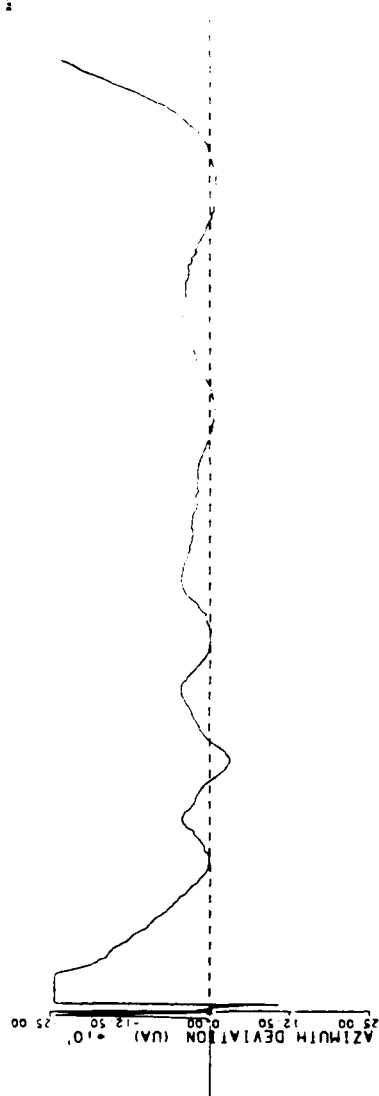
RUN # 14 SEP 65 WLS APP 5 RUN 35
 START TIME = 11:17:10
 STOP TIME = 11:17:12
 BARO SET = 30.31
 AZIMUTH = 3.50
 ELEVATION = 6.00
 WIND DIRECTION = 240
 WIND SPEED = 14



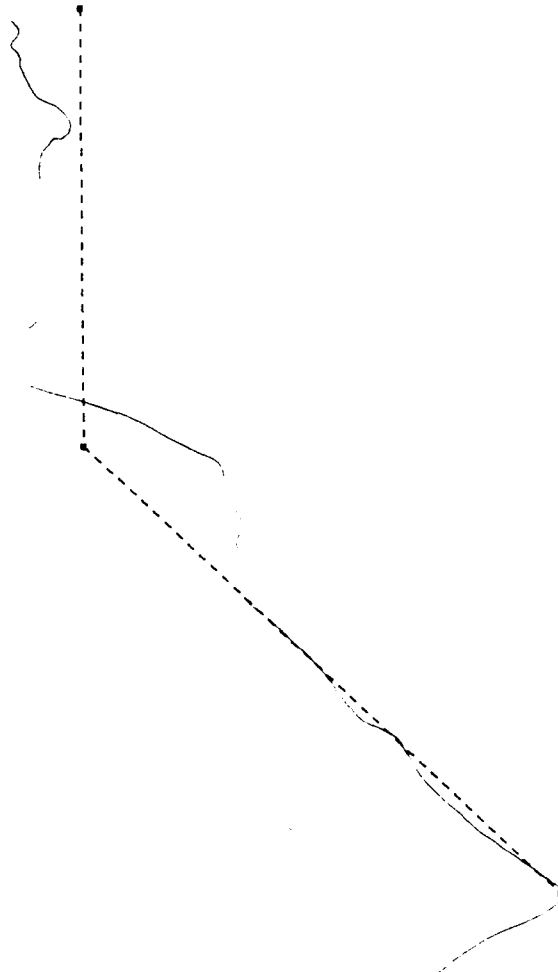
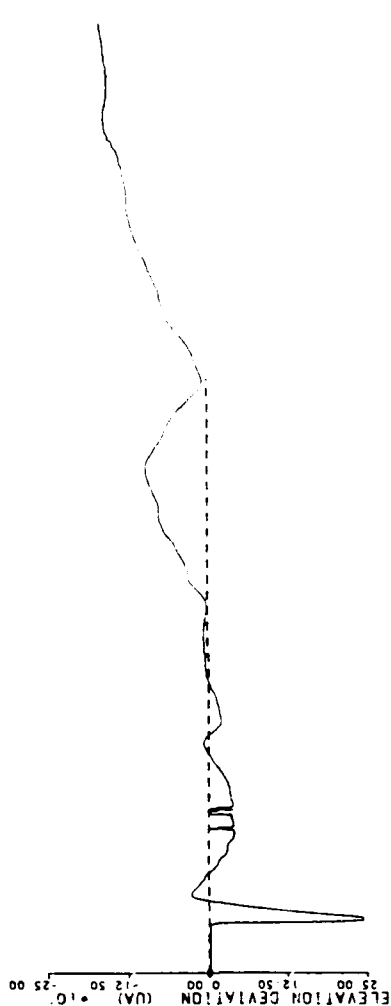
ELEVATION DEVIATION (UAV) -10 -25 50



RUN # 1
 STRIKE 4-SEP 85 05:05 AM 5 RUN 35
 START TIME = 13:15.5
 STOP TIME = 14:20
 ALTITUDE = 59.9
 ELEVATION = 3.50
 WIND DIRECTION = 290
 WIND SPEED = 12

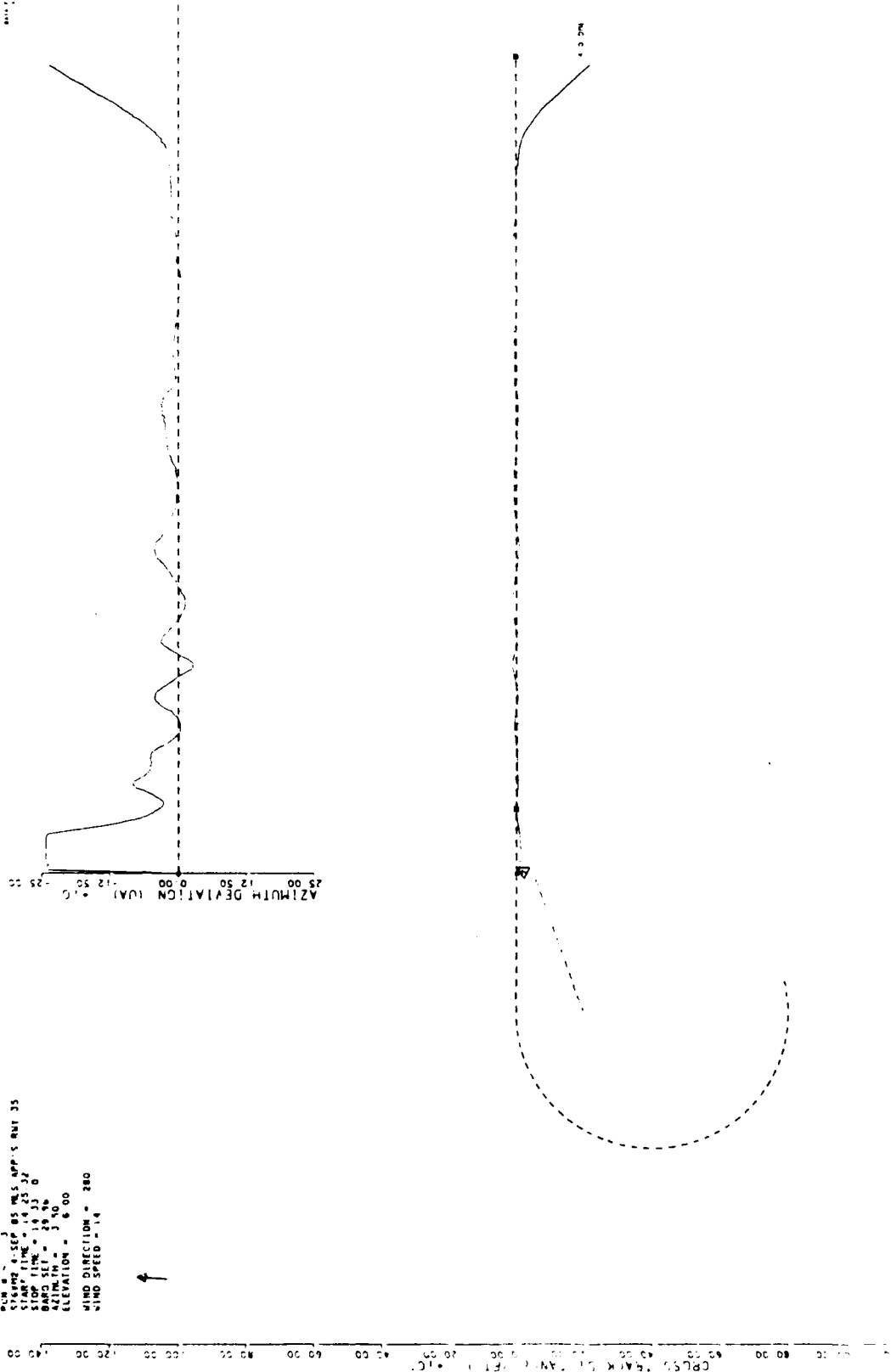
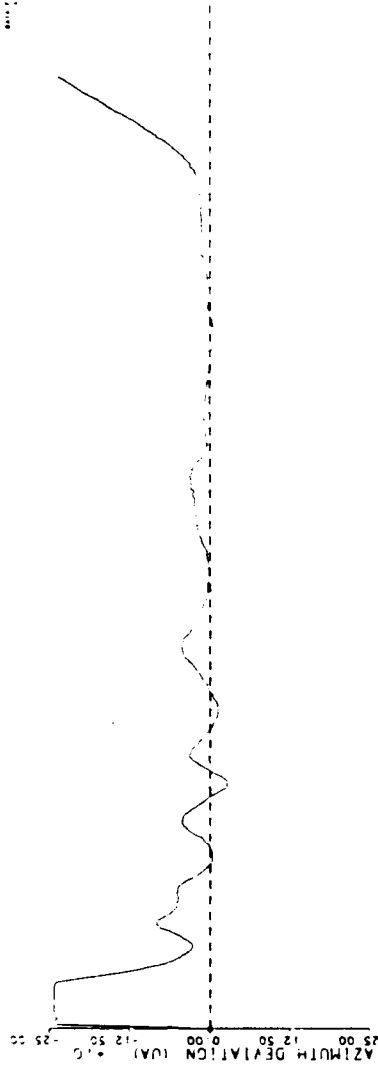


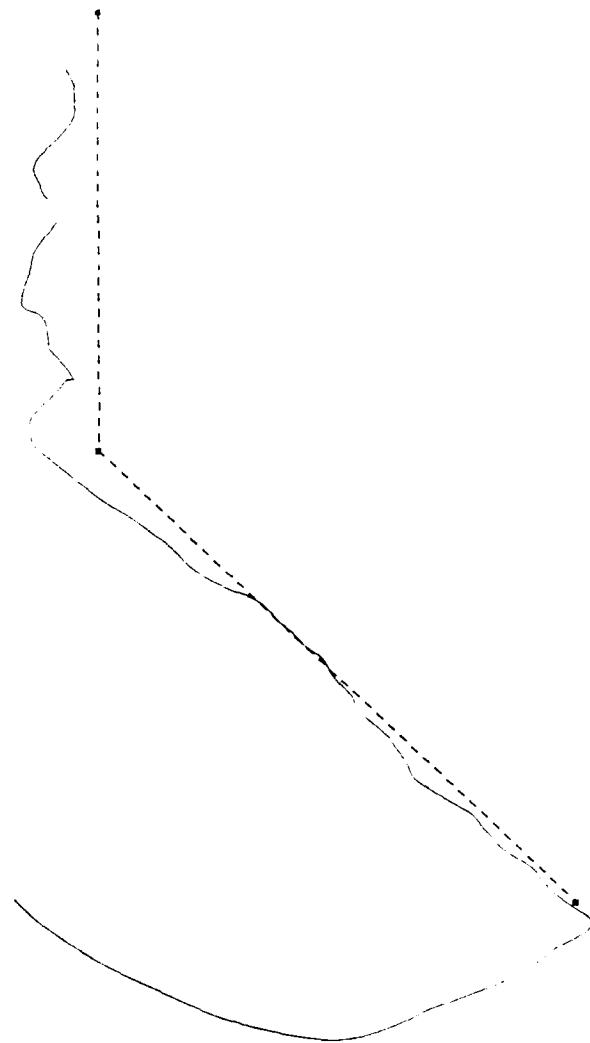
RUN # 1
 START TIME - 14 35 12
 STOP TIME - 14 35 12
 SARG SET - 29 46
 AZIMUTH - 3 40
 ELEVATION - 6 00
 WIND DIRECTION - 280
 WIND SPEED - 14



RUN # 3
 STARTING 4-SEP-85 MSL APP'S RUN 35
 START TIME = 14 23 32
 STOP TIME = 14 33 00
 DISTANCE = 3.50
 AZIMUTH = 3.50
 ELEVATION = 6.00

WIND DIRECTION = 280
 WIND SPEED = 14

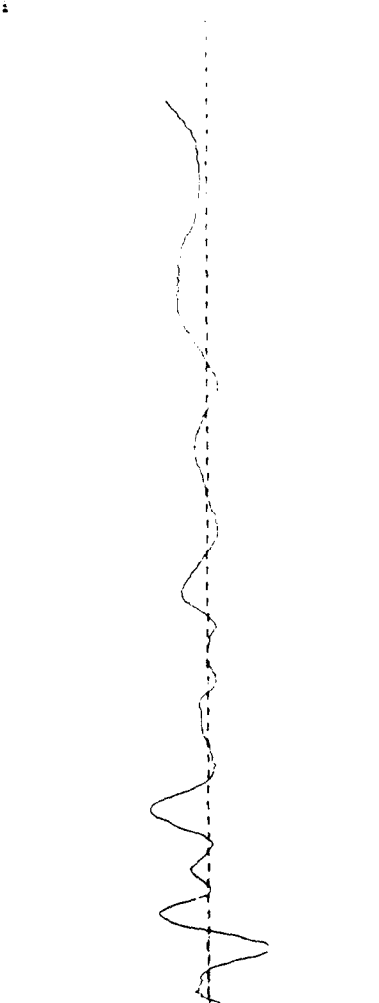


[illegible]

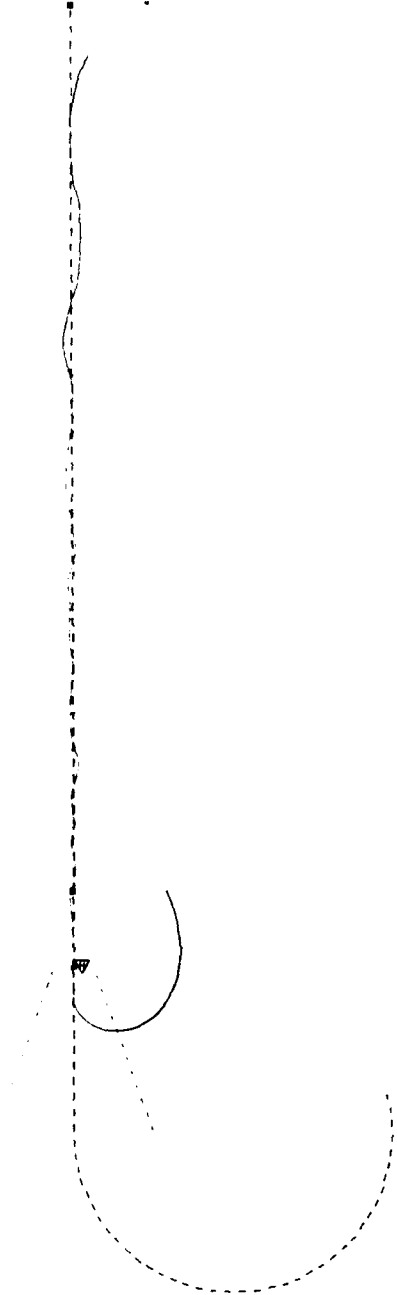
ALIGN TRACK DISTANCE (FT) - 10

PLAN P
 STORM 4 SEP 85 MES APP 5 RHY 35
 START TIME = 15 210
 BARO SET = 29.84
 AZIMUTH = 3 50
 ELEVATION = 6 50
 WIND DIRECTION = 290
 WIND SPEED = 13

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 AZIMUTH DEVIATION (UVA)

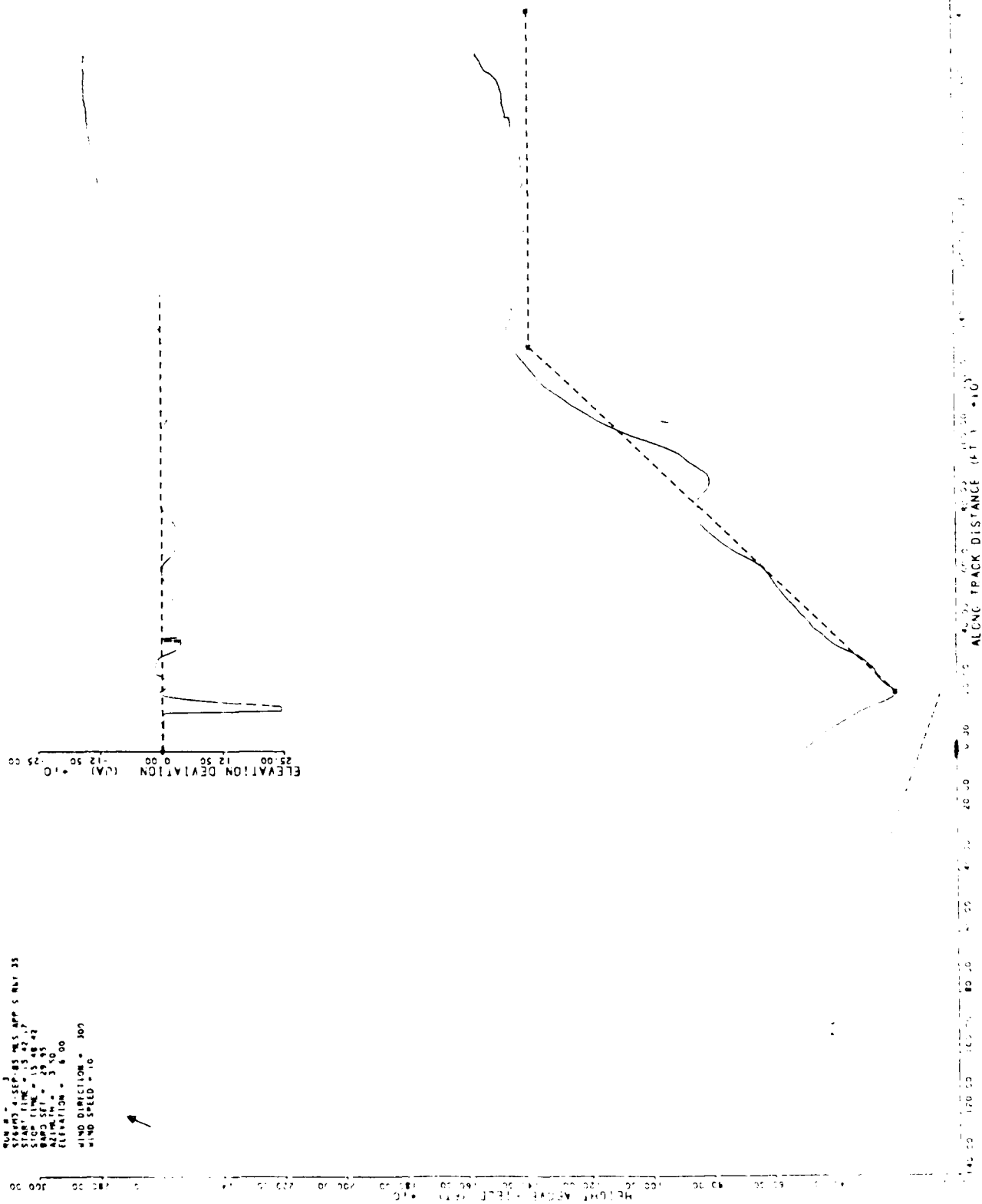


4.5 DN

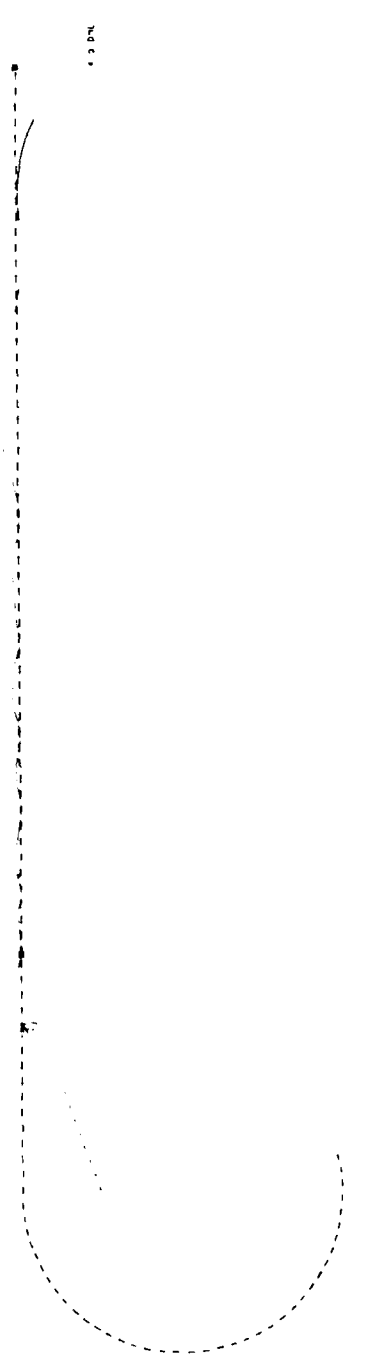
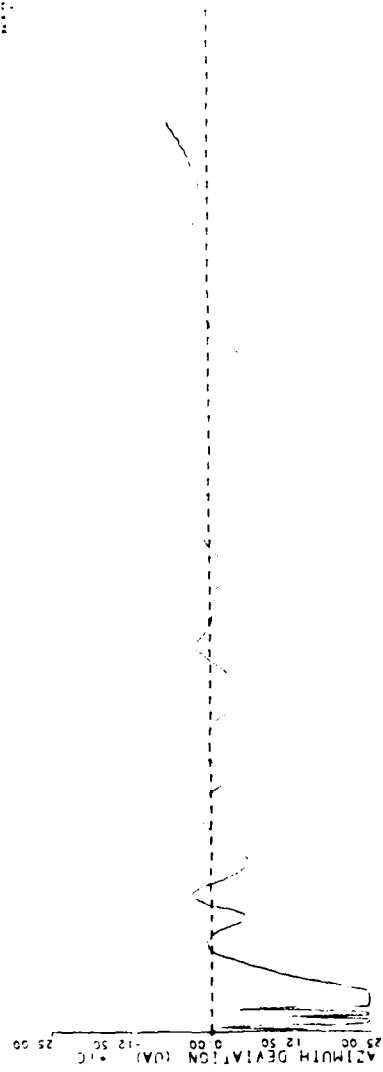


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ELEVATION DEVIATION (UA)

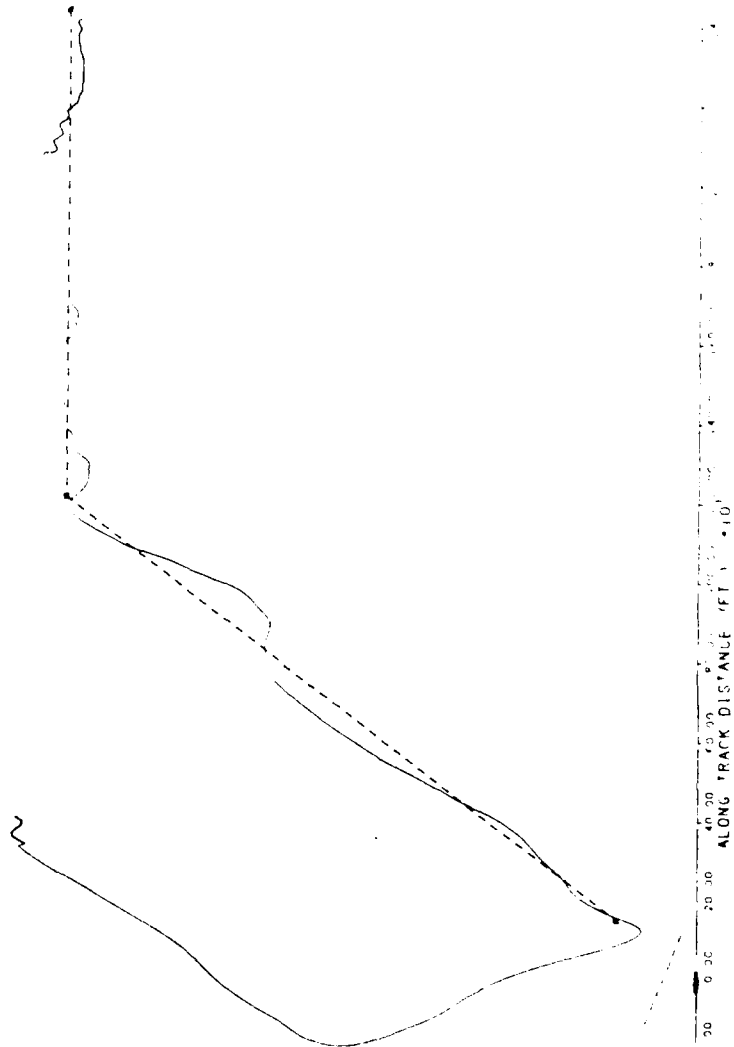
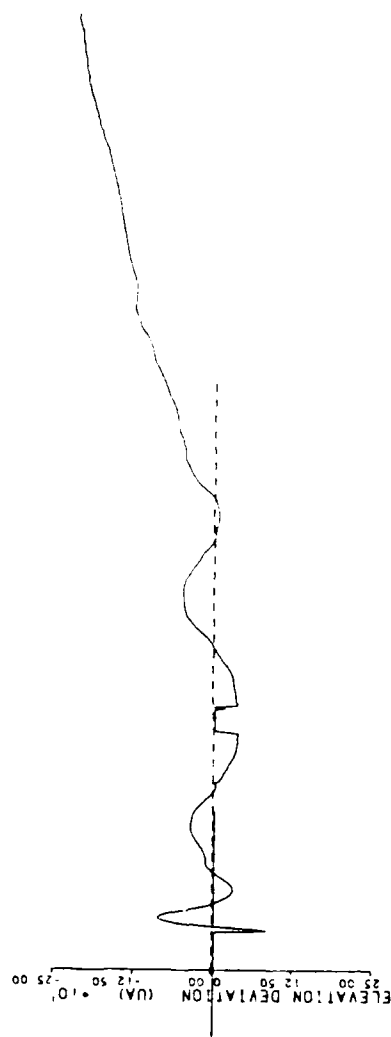


PLAN 8
 CHARGE - 8500
 TIME - 15:48:42
 SIGHT - 15:48:42
 RANGE - 15.00
 AZIMUTH - 150
 ELEVATION - 5.00
 WIND DIRECTION - 100
 WIND SPEED - 10

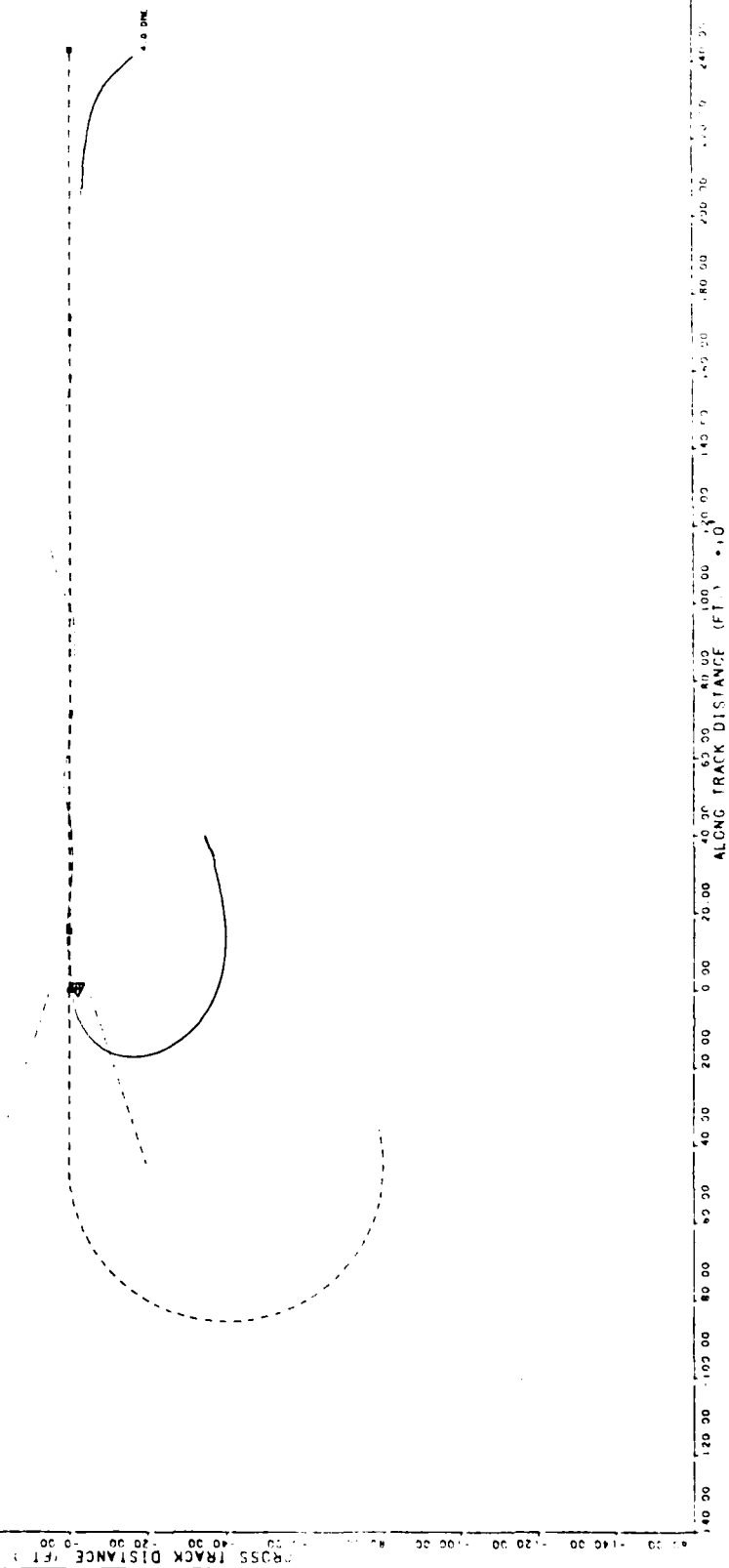
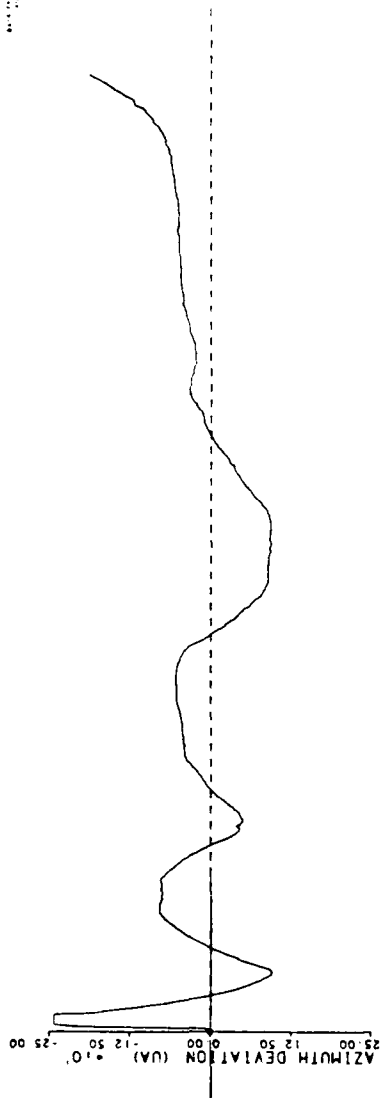


0.00 10.00 20.00 30.00 40.00 50.00 60.00 70.00 80.00 90.00 100.00
 ALONG TRACK DISTANCE (FT)

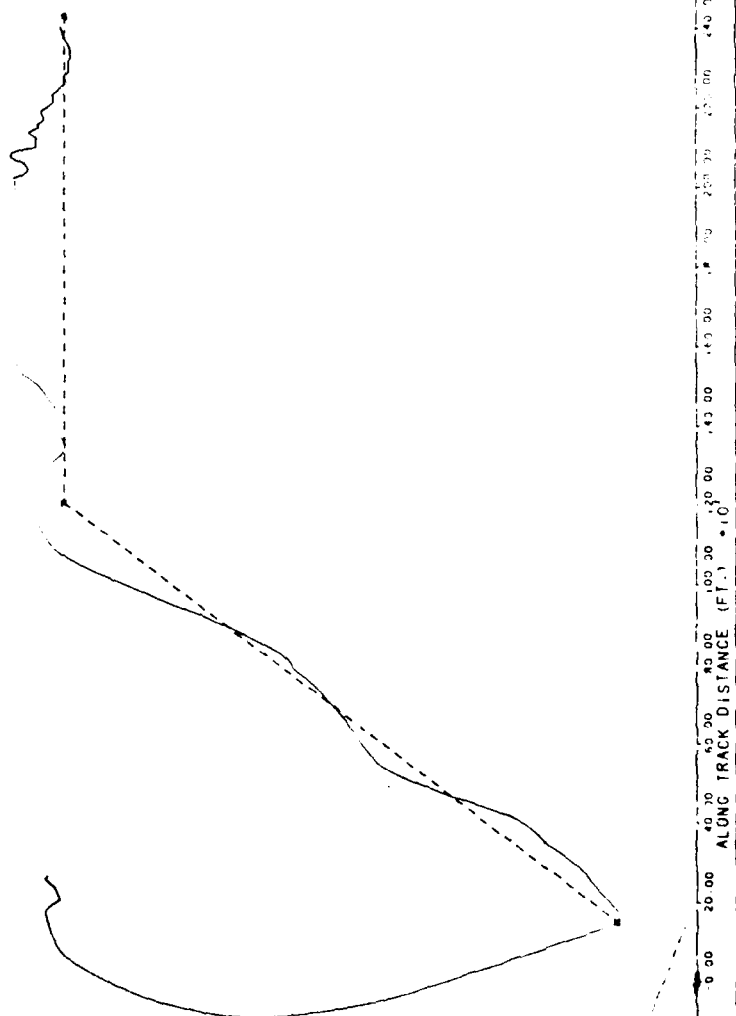
RUN # 2
 START TIME - 08:00
 STOP TIME - 10:45
 BARO SET - 30.01
 ALTITUDE - 350
 ELEVATION - 280
 WIND DIRECTION - 280
 WIND SPEED - 11



SYSTEM 4 SEP 85 MCS APP 5 NUT 35
 START TIME = 10 19 20
 STOP TIME = 10 26 12
 ALTITUDE = 3000
 ELEVATION = 7 50
 WIND DIRECTION = 280
 WIND SPEED = 11

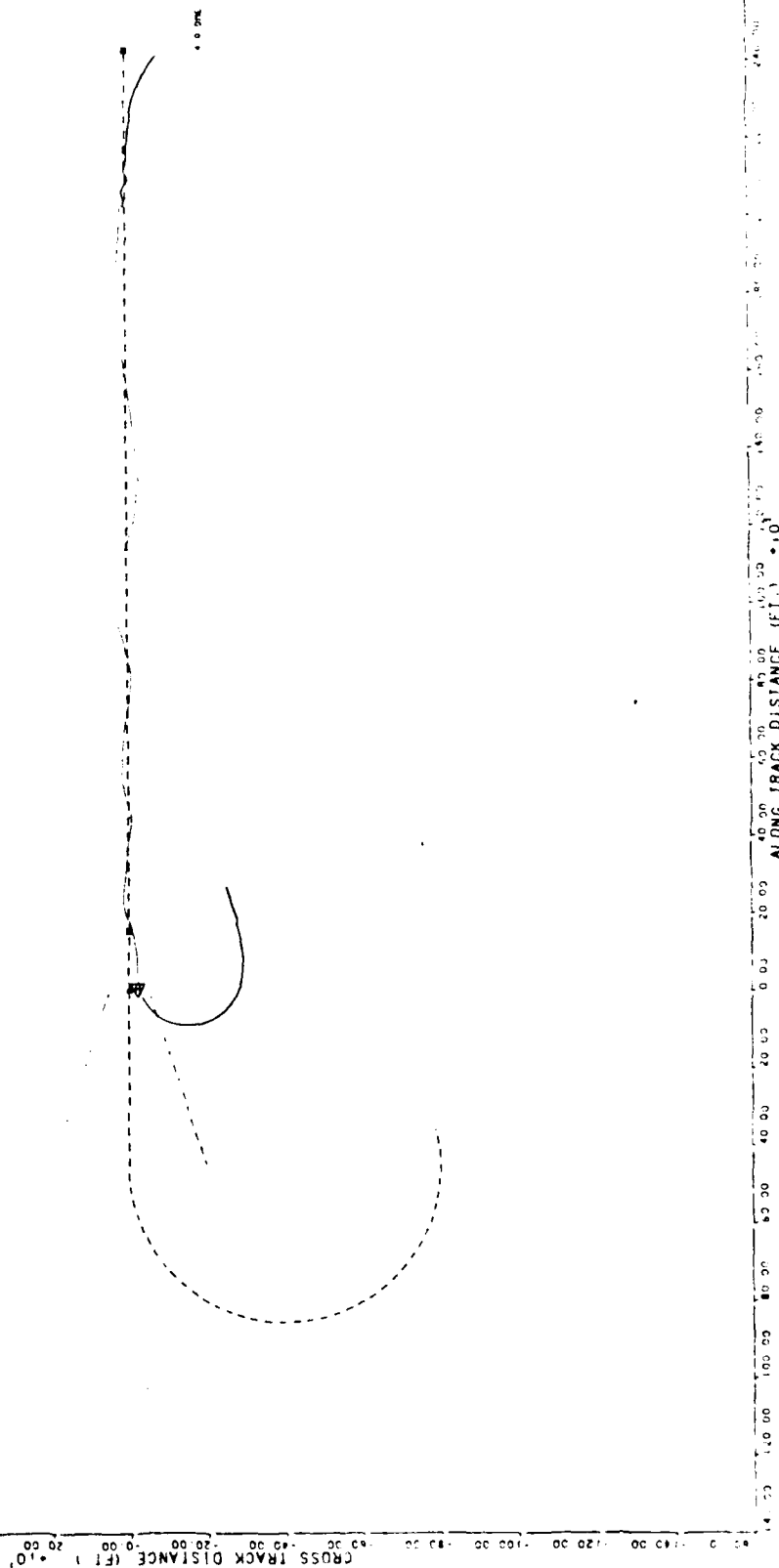
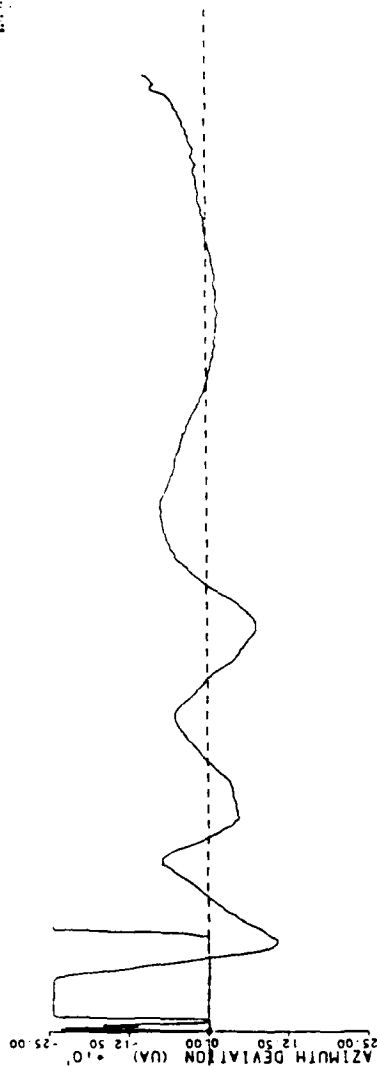


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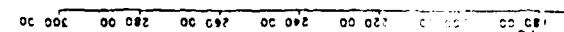


100 00 20 00 40 00 60 00 80 00 100 00 120 00 140 00 160 00 180 00 200 00 220 00 240 00 260 00 280 00 300 00 320 00 340 00 360 00 380 00 400 00 420 00 440 00 460 00 480 00 500 00 520 00 540 00 560 00 580 00 600 00 620 00 640 00 660 00 680 00 700 00 720 00 740 00 760 00 780 00 800 00 820 00 840 00 860 00 880 00 900 00 920 00 940 00 960 00 980 00 1000 00

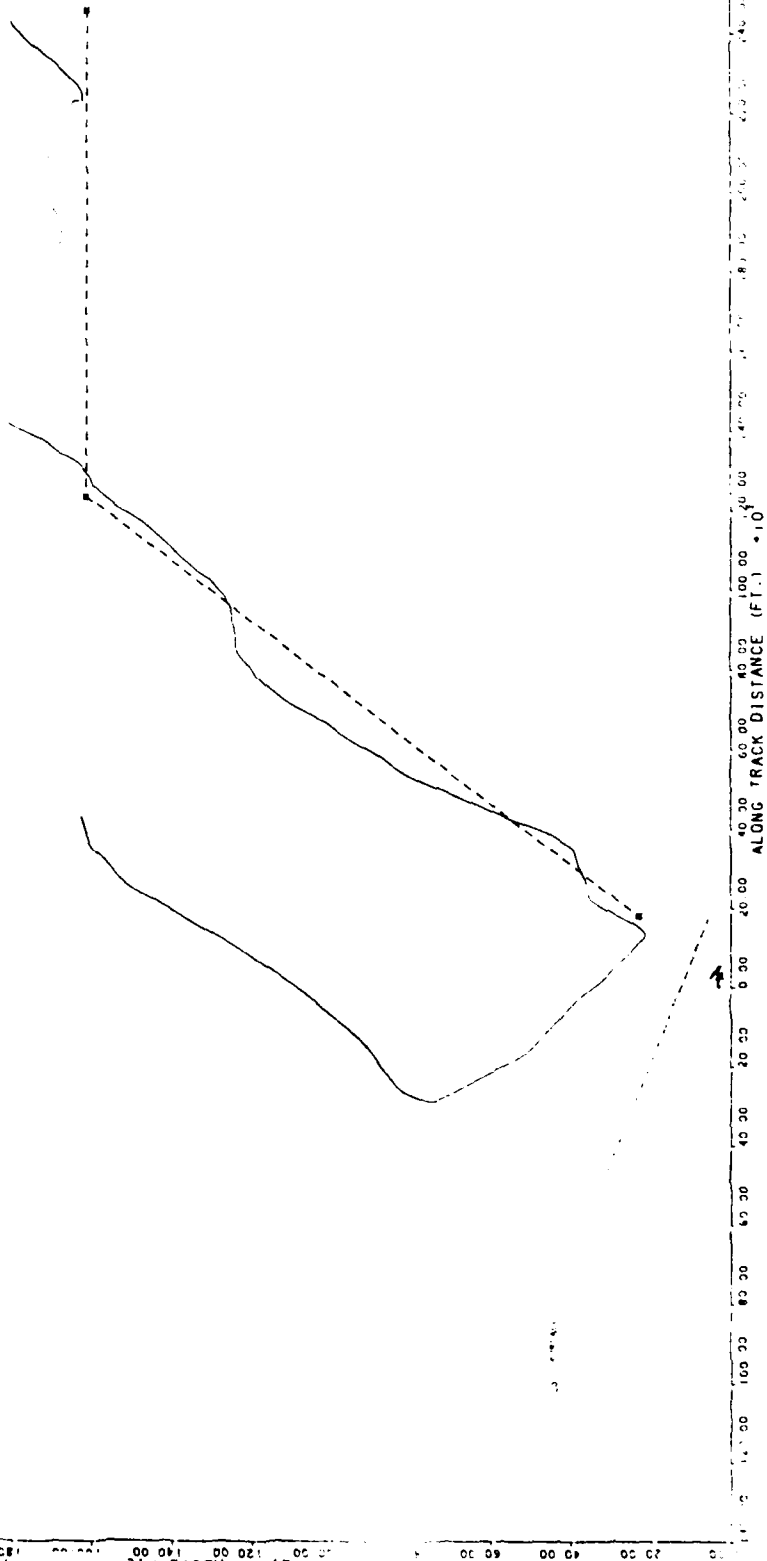
4-SEP-85 05:15:35
 START TIME = 10:46
 END TIME = 10:51:15
 WIND SET = 30 01
 AZIMUTH = 3 50
 ELEVATION = 7.50
 WIND DIRECTION = 260
 WIND SPEED = 10

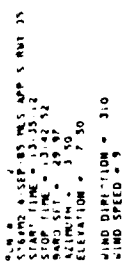


DATA PROCESSING - 20 - 4 - 3000

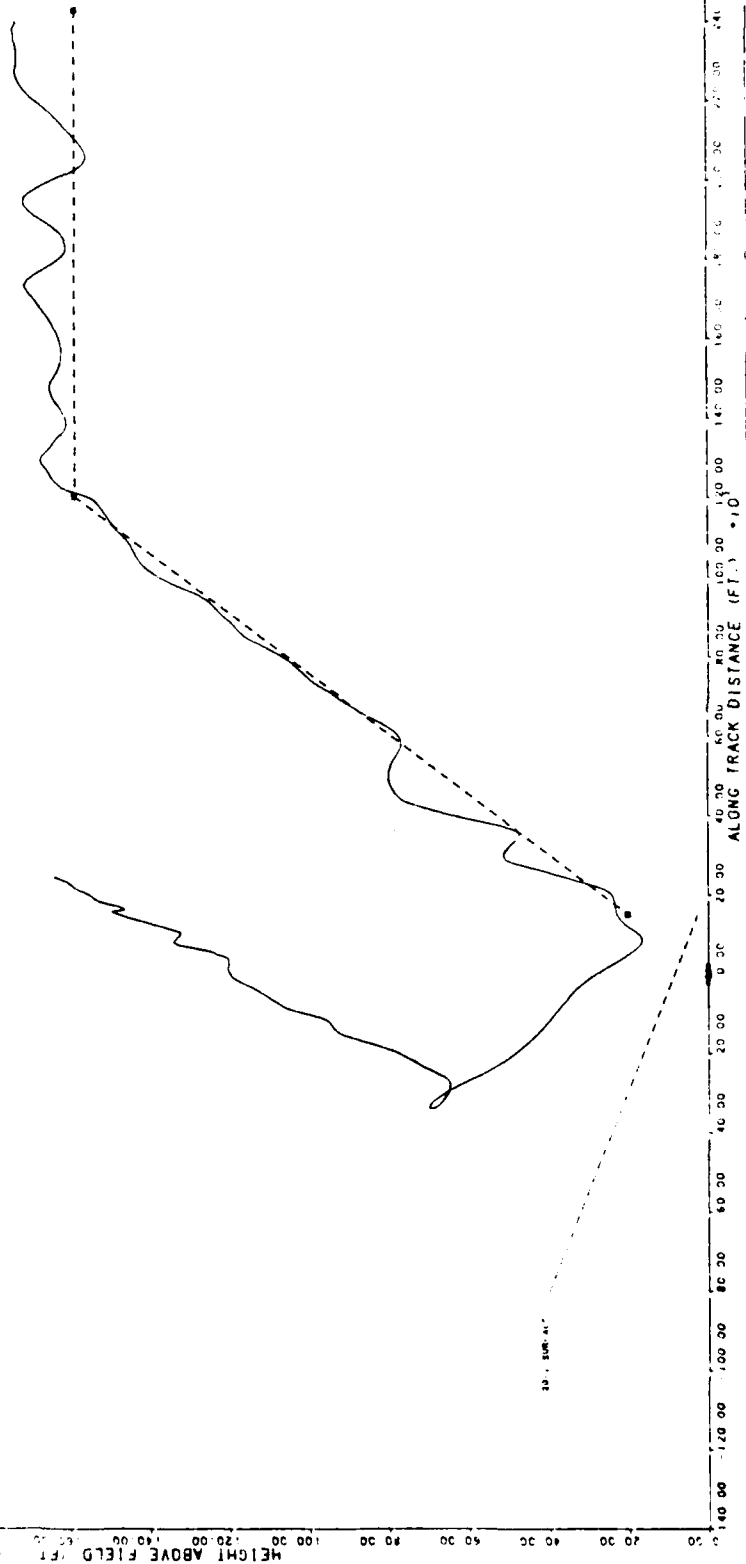
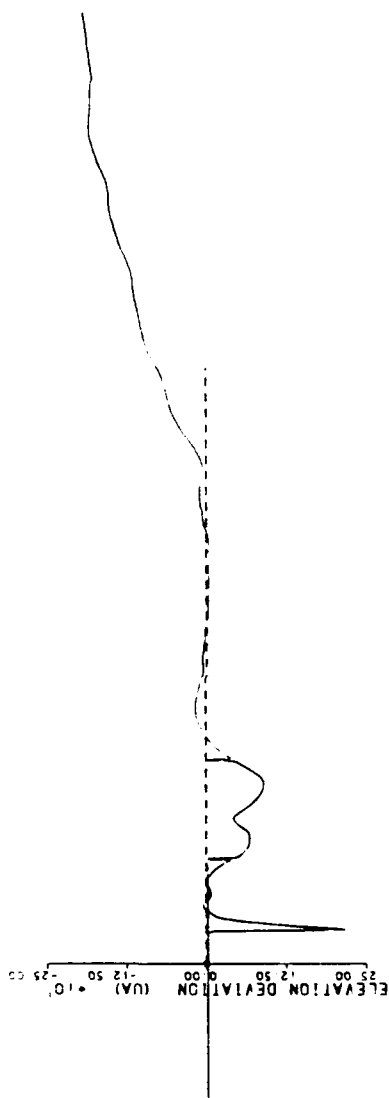


HEIGHT ABOVE FL 120 00 140 00

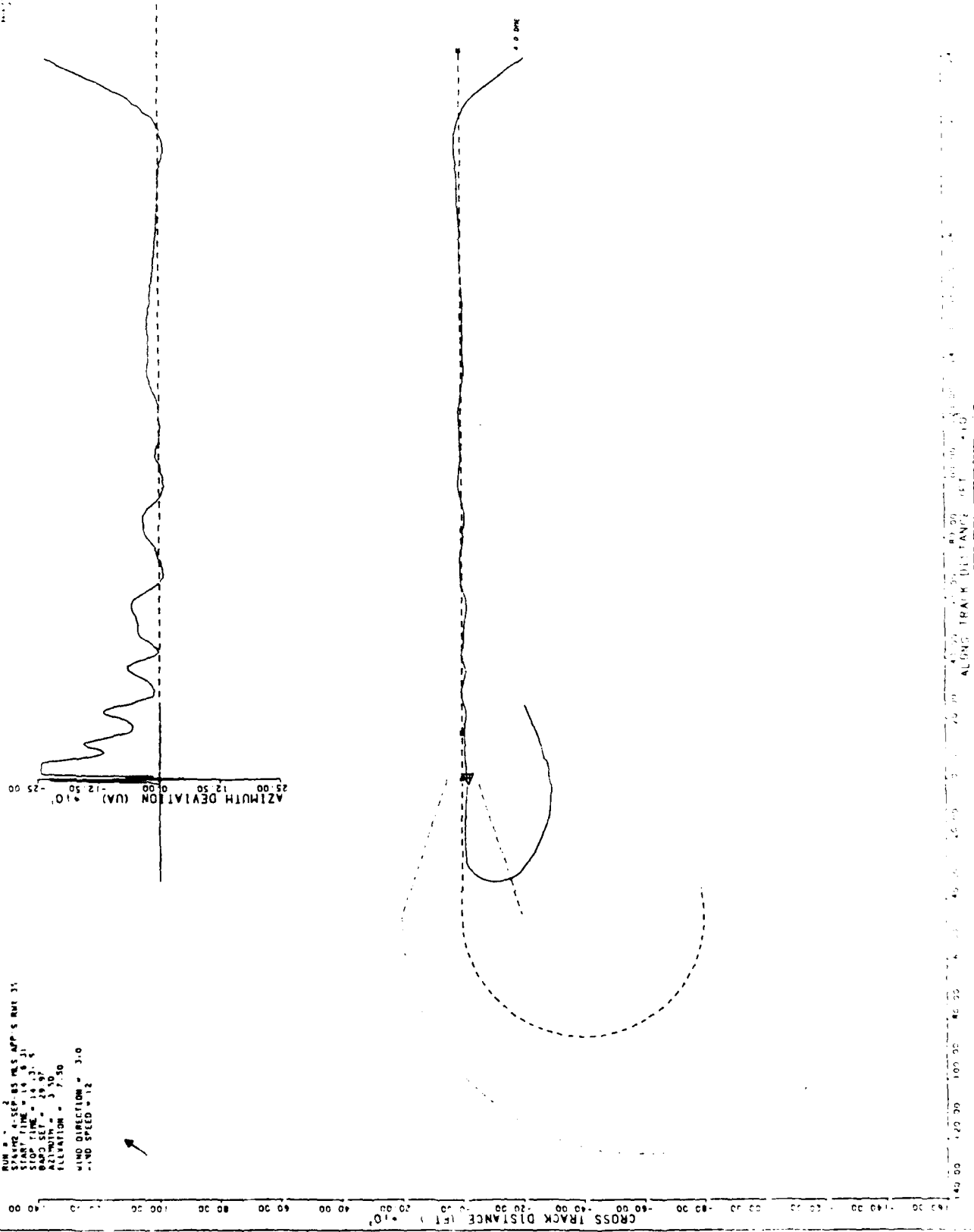


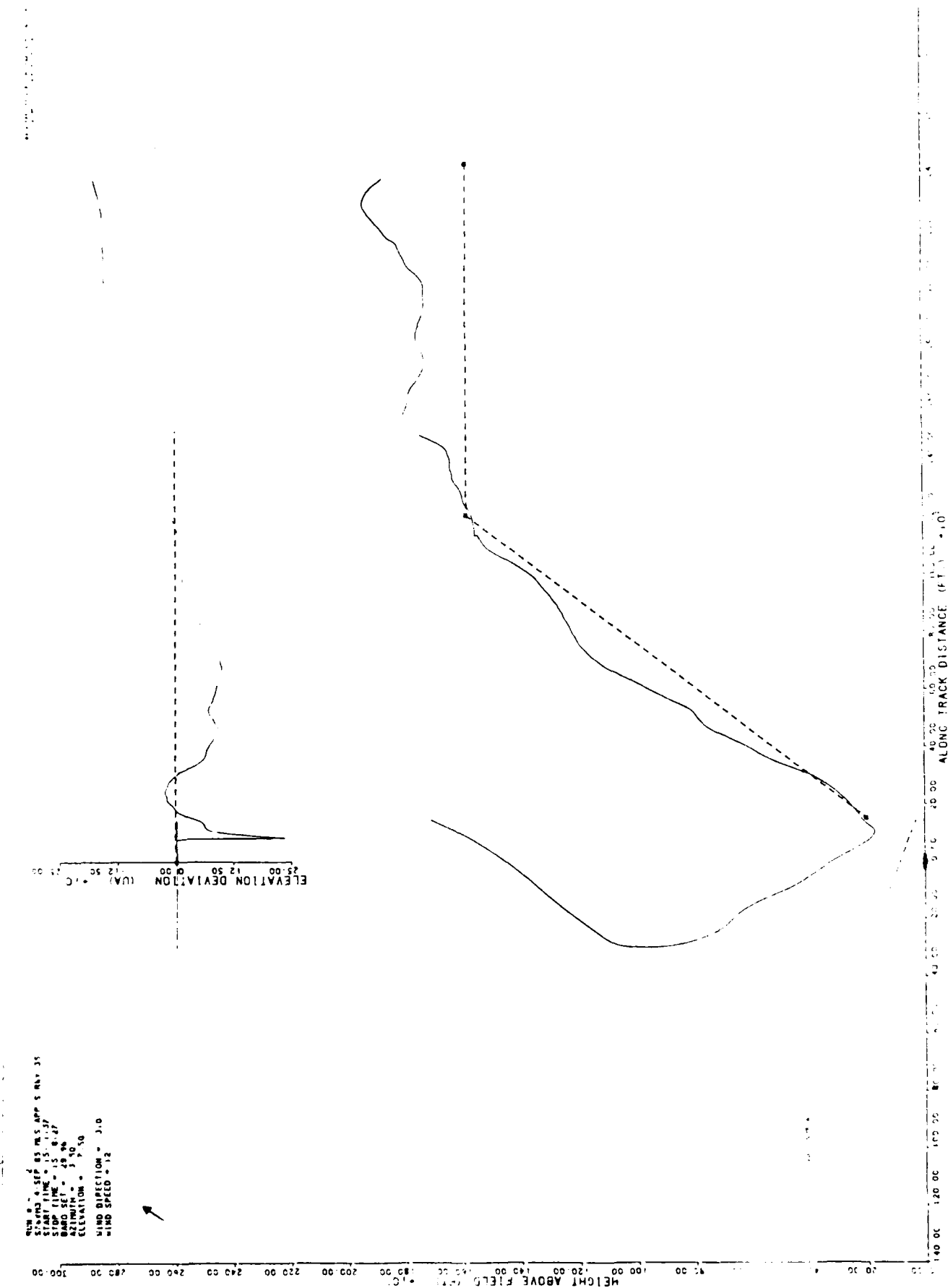


RUN 8 - 2
 START TIME - 05 JUL 55
 STOP TIME - 15 13 4
 BARO SET - 29.97
 AZIMUTH - 350
 ELEVATION - 7.0
 WIND DIRECTION - 210
 WIND SPEED - 12



RUN 8 - 2
 STARTING 4-SEP-85 PLS APP 5 RUN 35
 START TIME = 14 03 21
 STOP TIME = 14 03 5
 WIND DIRECTION = 300
 WIND SPEED = 12
 ELEVATION = 7.50
 WIND DIRECTION = 300
 WIND SPEED = 12





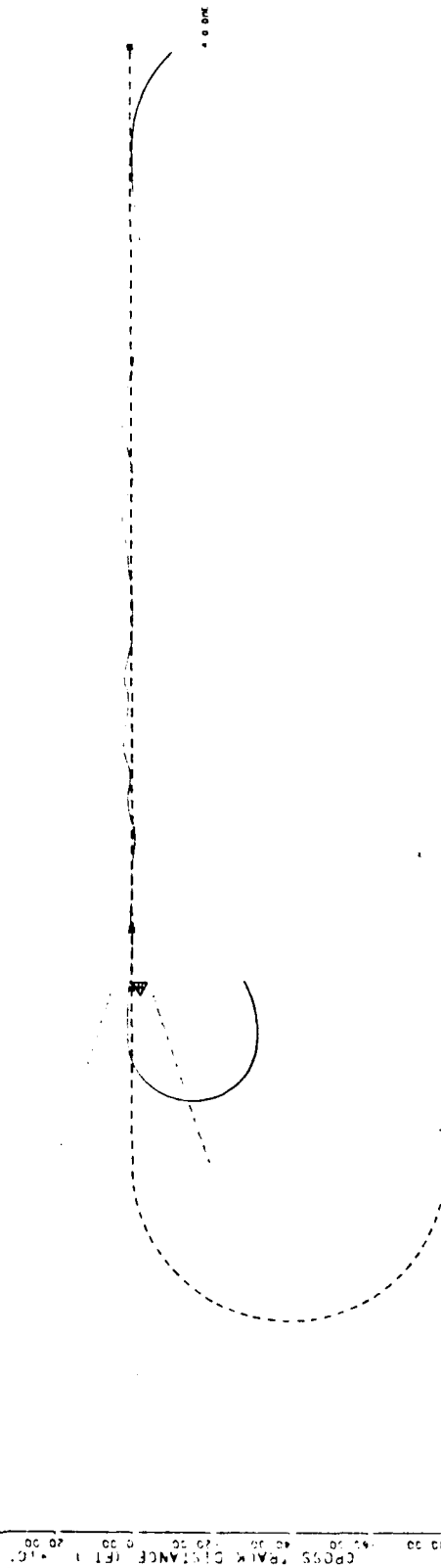
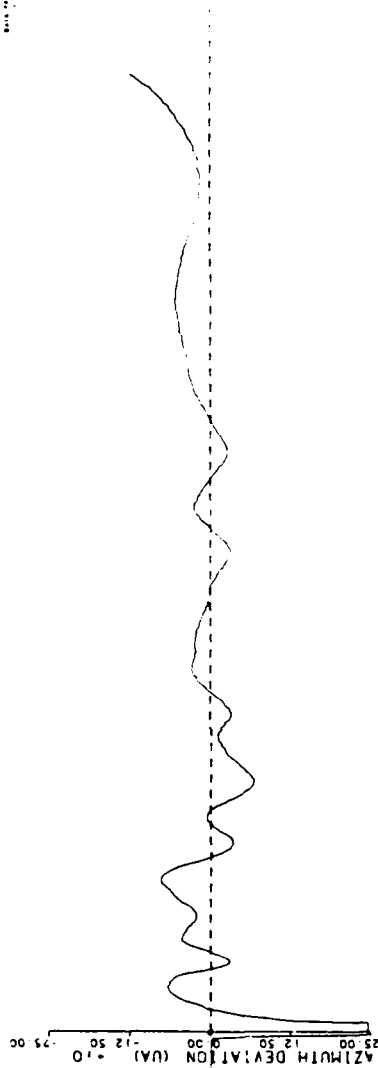
RUN # 2
 START TIME - SEP 85 15:00
 STOP TIME - 15:25
 BARO SET - 29.95
 AZIMUTH - 350
 ELEVATION - 7.40
 WIND DIRECTION - 300
 WIND SPEED - 10

ELEVATION DEVIATION (GA) *10
 25.00
 12.50
 0.00
 -12.50
 -25.00

HEIGHT ABOVE FIELD (FT) *10
 300.00
 280.00
 260.00
 240.00
 220.00
 200.00
 180.00
 160.00
 140.00
 120.00
 100.00
 80.00
 60.00
 40.00
 20.00
 0.00

ALTIM. TRACK DISTANCE (FT) *10
 140.00
 120.00
 100.00
 80.00
 60.00
 40.00
 20.00
 0.00
 20.00
 40.00
 60.00
 80.00
 100.00
 120.00
 140.00

RUN 2
 STARTED 4 SEP 65 HRS APP 5.00
 START TIME 15.22.23
 STOP TIME 15.29.5
 BAND SET 29.85
 ALTITUDE 3.50
 ELEVATION 3.50
 WIND DIRECTION 300
 WIND SPEED 10

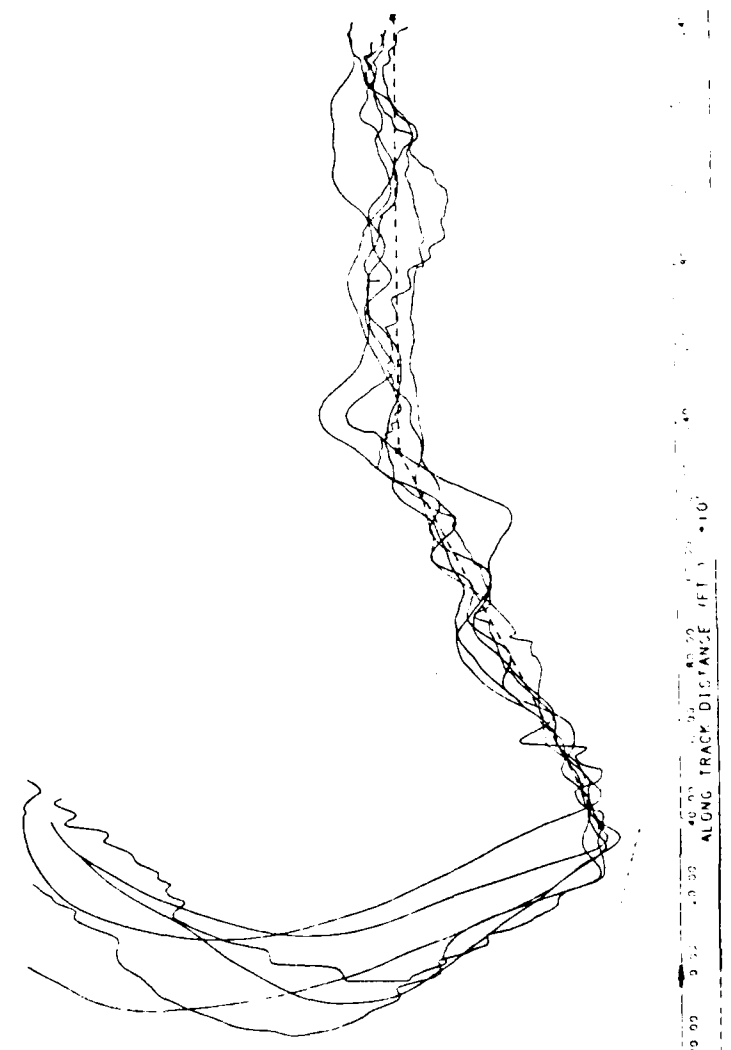
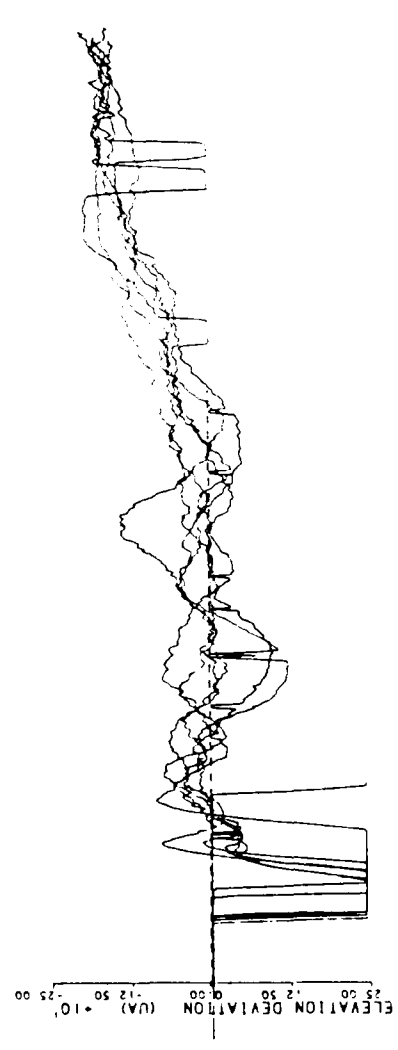


DRAFT - 10

ATTACHMENT 4.
COMPOSITE PLOTS

DATA FROM 100 S. 1000' W. 100' N. 100' E.

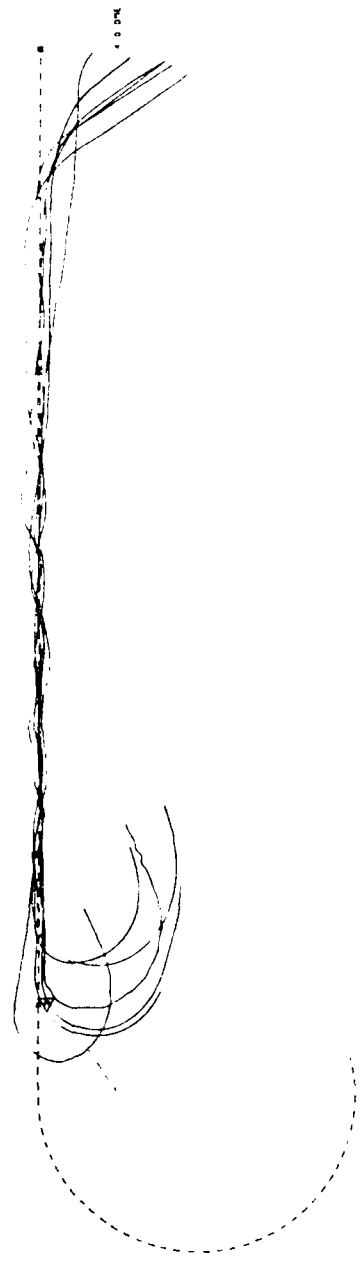
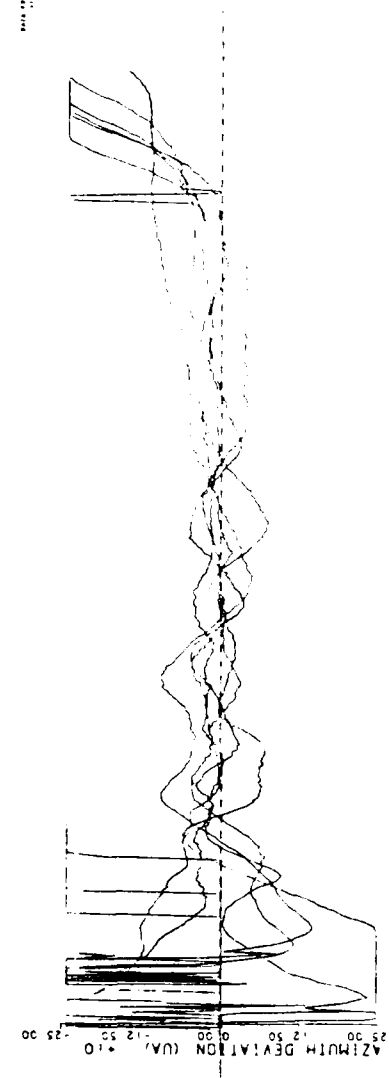
STATION 1, 4 SEP 85 3 DEC 85 5 APP 5 RUTTS 4015 8 MAP
MISSED APPROACH



0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340 360 380 400 420 440 460 480 500 520 540 560 580 600 620 640 660 680 700 720 740 760 780 800 820 840 860 880 900 920 940 960 980 1000

SC 60101, 4 SEP 83 3 DEC 83 APP 5 RV135 40125 0 MAP
 MISSED APPROACH

CROSS TRACK DISTANCE (FT) 0.00 20.00 40.00 60.00 80.00 100.00 120.00 140.00 160.00 180.00 200.00 220.00 240.00 260.00 280.00 300.00 320.00 340.00 360.00 380.00 400.00 420.00 440.00 460.00 480.00 500.00 520.00 540.00 560.00 580.00 600.00 620.00 640.00 660.00 680.00 700.00 720.00 740.00 760.00 780.00 800.00 820.00 840.00 860.00 880.00 900.00 920.00 940.00 960.00 980.00 1000.00



ALONG TRACK DISTANCE (FT) 0.00 20.00 40.00 60.00 80.00 100.00 120.00 140.00 160.00 180.00 200.00 220.00 240.00 260.00 280.00 300.00 320.00 340.00 360.00 380.00 400.00 420.00 440.00 460.00 480.00 500.00 520.00 540.00 560.00 580.00 600.00 620.00 640.00 660.00 680.00 700.00 720.00 740.00 760.00 780.00 800.00 820.00 840.00 860.00 880.00 900.00 920.00 940.00 960.00 980.00 1000.00

AD-A175 487

EVALUATION OF SIKORSKY S-76A 24 MISSED APPROACH
PROFILES FOLLOWING PRECIS (U) FEDERAL AVIATION
ADMINISTRATION TECHNICAL CENTER ATLANTIC CIT

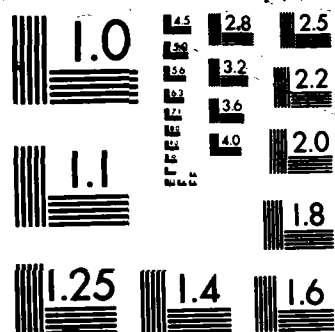
2/2

UNCLASSIFIED

M M WEBB OCT 86 DOT/FAA/CT-TN86/31 T87018 F/G 17/7

NL





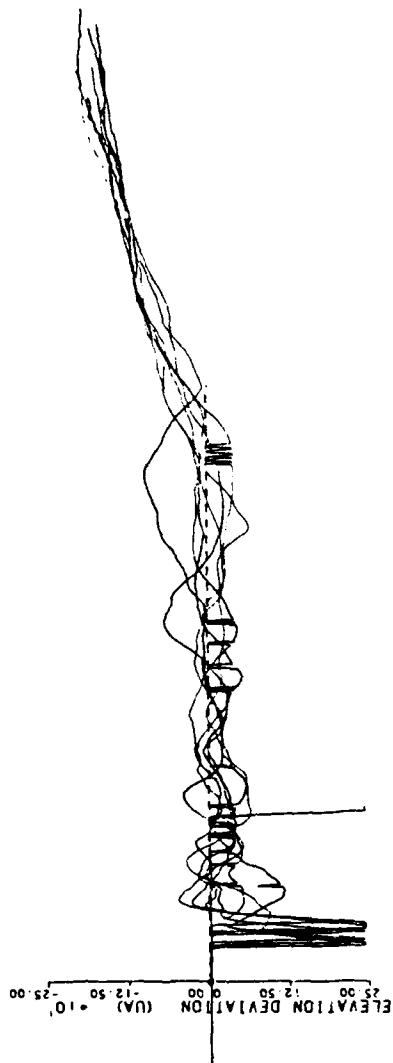
XERO COPY RESOLUTION TEST CHART

100 00 200 00 300 00 400 00 500 00 600 00 700 00 800 00 900 00 1000 00

ELEVATION DEVIATION (UA) * 10⁻¹

25.00 12.50 0.00 -12.50 -25.00

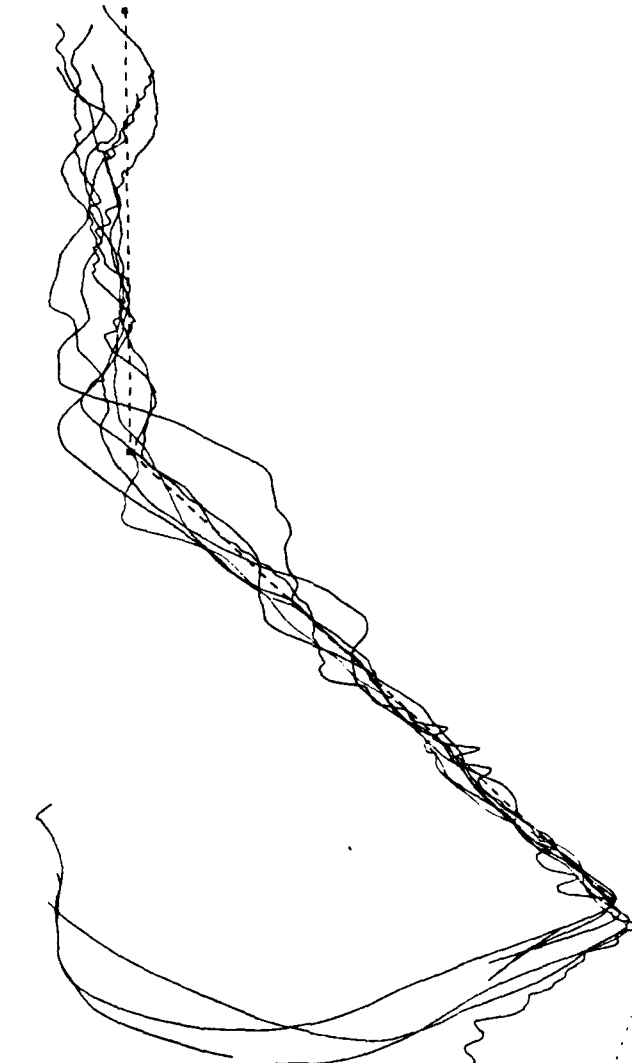
STATION 1 4-SEP 85 800G WLS APP 1.8 NVIS 35 40KTS
MISSED APPROACH



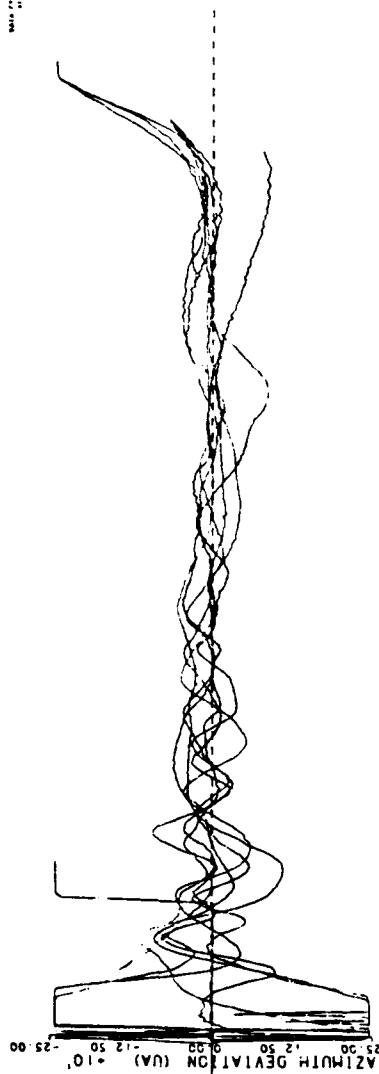
100 00 200 00 300 00 400 00 500 00 600 00 700 00 800 00 900 00 1000 00

ELEVATION DEVIATION (UA) * 10⁻¹

25.00 12.50 0.00 -12.50 -25.00



17 SEP 65 05 40G NLS APP'S RVT35 4015
MISSED APPROACH



E-44

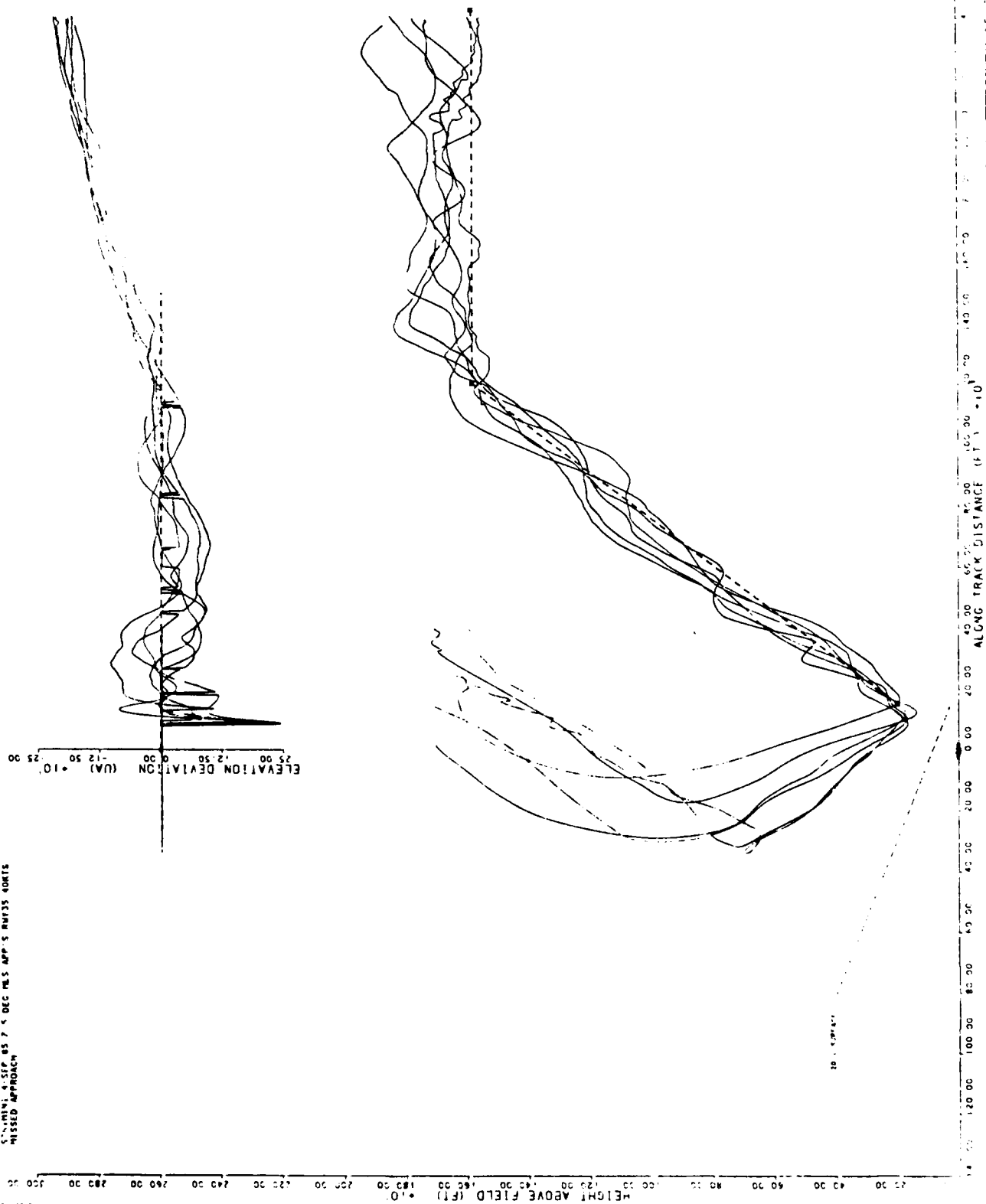
CROSS TRACK DISTANCE (FT) *10'



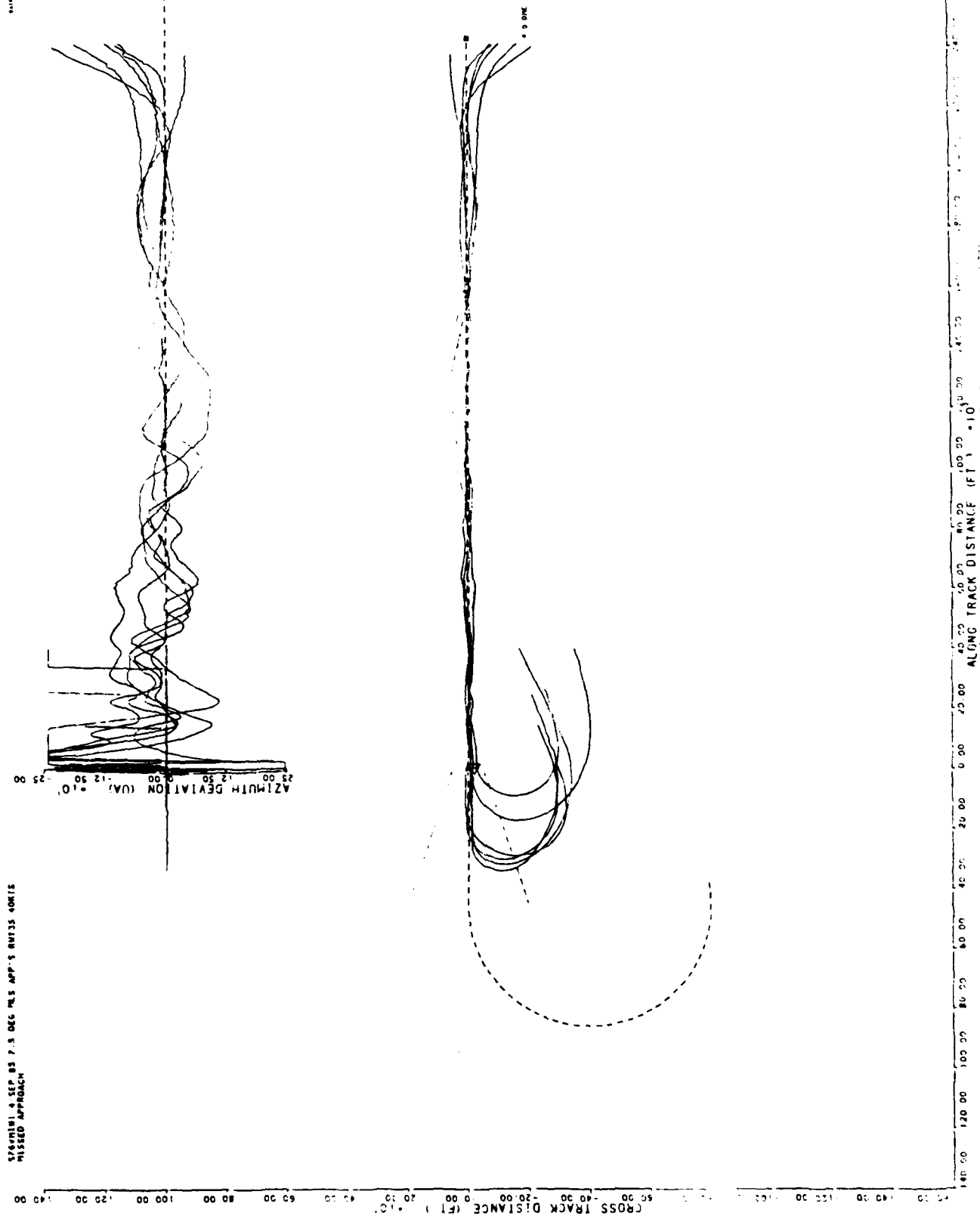
ALONG TRACK DISTANCE (FT) *10'

DATA REPORTED BY: [illegible]
DATE: 11 SEP 65

STATION: 4 SEP 65 7 5 DEC 1965 APP 5 MISS 40RTS
MISSED APPROACH



SPAWNED 4 SEP 85 7:50 PM'S APP'S BUTTS ONTIS
MISSED APPROACH



END

2-87

DTIC